University of Alberta

BULL TROUT (*Salvelinus confluentus*) IN THE KAKWA RIVER WATERSHED: LINKING FISHERIES AND LAND MANAGEMENT USING RESOURCE SELECTION FUNCTIONS

By

Travis D. Ripley

A thesis submitted to the Faculty of Graduate Studies in partial fulfilment of the requirements for the Degree of Master of Science

in

Environmental Biology and Ecology
Department of Biological Science

Edmonton, Alberta
Spring 2003

University of Alberta

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-82337-7

Canada

University of Alberta

Library Release Form

Name of Author: Travis D. Ripley

Title of Thesis: Bull Trout (*Salvelinus confluentus*) in the Kakwa River Watershed: Linking Fisheries and Land Management Using Resource Selection Functions

Degree: Master of Science

Year this Degree Granted: 2003

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

10320 – 99th Street, Box 24
Provincial Building
Grande Prairie, Alberta, Canada
T8V 6J4

April 9 03

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for the acceptance, a thesis entitled Bull Trout (*Salvelinus confluentus*) in the Kakwa River Watershed: Linking Fisheries and Land Management using Resource Selection Functions submitted by Travis D. Ripley in partial fulfillment of the requirements for the Degree of Master of Science in Environmental Biology and Ecology

Dr. Mark S. Boyce

Dr. Joe Nelson

Dr. John Volpe

Dr. Lee Foote

Date: 26 March 2003

DEDICATION

In dedication to my daughter, I may have missed some of the firsts in her life, but I will not miss anymore.

ABSTRACT

Bull trout (*Salvelinus confluentus*) distribution and abundance were evaluated using resource selection functions in the Kakwa River watershed, Alberta. Presence of bull trout was more likely in higher stream orders, streams with low levels of fine sediments and low timber harvest. This model was used to evaluate responses of bull trout occurrence when timber harvest was simulated at 10%, 25%, 50% and 75% increases across the watershed. In each simulation, bull trout occurrence declined by 20% to 60%.

Zero-inflated poisson regression was used to show that bull trout abundance was higher at sites on higher stream orders, elevation, distance fished and fine sediment. Results from this research suggest risk to persistence of bull trout when timber harvest levels and road densities increase. In each case, increases in these anthropogenic perturbations resulted in loss of bull trout occurrence and density. Land management decisions should incorporate these landscape-level responses by bull trout if this species is to persist.

ACKNOWLEDGEMENTS

I wish to sincerely thank my wife Tammy, without her support, understanding, encouragement and friendship this wouldn't have been made possible.

I also thank Dave Walty who provided guidance and needed time to complete my research while working over the years. The educational leave program with the Government of Alberta also provided financial support.

Mark Boyce agreed to co-supervise and supported me from start to finish through three revisions of my thesis topic. Joe Nelson gave me encouragement and agreed to co-supervise without hesitation. John Volpe and Lee Foote endured through timeless gaps between committee meetings and provided support to my research.

Paul Hvenegaard with the Alberta Conservation Association supplied timely needed data and advice from his in depth knowledge of the Kakwa River watershed. Garry Scrimgeour has faithfully allowed me to pursue this research despite his desire to move forward with his own endeavours. All members of the Northern Watershed Project supported my use of partial data in fulfillment of this research.

My fellow lab mates provided not only comic relief but also an understanding of all facets of my research, especially Scott Nielson whose statistical advice and understanding cannot go without mention.

Finally I would be remiss if I didn't acknowledge Tim Hortons™. They always had a cup of warm coffee ready whether it was 5:30 am or 11:30 pm.

TABLE OF CONTENTS

ABSTRACT

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 1
GENERAL INTRODUCTION 1

PURPOSE AND OBJECTIVES 4

LITERATURE CITED 5

CHAPTER 2 8
EVALUATING BULL TROUT (*Salvelinus confluentus*) DISTRIBUTION USING RESOURCE SELECTION FUNCTIONS 8

INTRODUCTION 8

STUDY AREA 11

METHODS 14
Field Collections 14
Bull Trout 14
Stream Attributes 15
Watershed Characteristics 17

STATISTICAL ANALYSIS 18
Model Development 18
Model Selection and Validation 19

RESULTS 21
Bull Trout Distribution 21
Occurrence Models 25
Habitat models 26
GIS models 26
Human Disturbance models 27
Model Combinations 28

DISCUSSION 34

REFERENCES 39

APPENDIX 1 43

CHAPTER 3 45
BULL TROUT (*Salvelinus confluentus*) HABITAT USE IN THE KAKWA RIVER WATERSHED, ALBERTA: LINKING OCCURRENCE AND ABUNDANCE 45

INTRODUCTION 45

STUDY AREA 47

METHODS 50
Data Collection 50
Statistical Analysis 50

RESULTS 53

DISCUSSION 57

REFERENCES 60

CHAPTER 4 62

CONCLUSION 62

REFERENCES 66

LIST OF TABLES

Table 1. Species distribution list in the Kakwa River watershed, in alphabetical order. * denotes game fish..... 13

Table 2. Summary count of stream fish and habitat sample sites completed between 1994 and 2001. Sample sites are separated by stream order each year. 15

Table 3. Habitat variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed. 16

Table 4. Watershed variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed. 17

Table 5. Human disturbance variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed..... 18

Table 6. Candidate models describing bull trout presence and absence using habitat attributes (Table 3). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models. 26

Table 7. Candidate models describing bull trout presence and absence using GIS attributes (Table 4). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models. 27

Table 8. Candidate models describing bull trout presence and absence using human disturbance attributes (Table 5). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models..... 28

Table 9. Candidate models describing bull trout presence and absence. Each model type incorporates respective attributes based on physical habitat, GIS and human disturbance parameters. β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models. 29

Table 10. Comparison of ROC results and standard error from the three best models predicting bull trout distribution. Full model incorporates all data. Test model is the mean of five replicates for each model type calculated from randomly withheld data (50%)..... 30

Table 11. Response of sites presently with bull trout to simulated increases of timber harvest in the entire basin (all watersheds) and basins already harvested (harvested watersheds). 32

Table 12. Species distribution list in the Kakwa River watershed in alphabetical order. * denotes game fish..... 49

Table 13. Descriptive statistics for bull trout counts (number) and density (number bull trout/100 m). Large variance suggests over-dispersion of the data. 54

Table 14. Zero inflated models evaluating bull trout abundance. Each model type incorporates respective attributes based on occurrence model results. β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models, Z is the vuong test statistic..... 54

Table 15. Differences in beta values from the best occurrence model (non-inflated) and the inflated portion of this model identifying density of bull trout..... 55

LIST OF FIGURES

Figure 1. Kakwa River watershed in northwestern Alberta..... 12

Figure 2. Ecoregions comprising the Kakwa River watershed..... 13

Figure 3. Proportion of sample sites represented by the proportion of each stream order by length. Therefore, 41% of sample sites were evaluated within the proportion of first order streams within the Kakwa River watershed..... 15

Figure 4. Distribution of sample sites (n=300) across the Kakwa River drainage 21

Figure 5. Distribution of sample sites by stream order within the Kakwa River watershed 22

Figure 6. Description of bull trout captures by stream order in the Kakwa River watershed 22

Figure 7. Percent of bull trout captures and water temperatures based on elevation classes (100 m interval) 23

Figure 8. Bull trout captures by site based on elevation classes (100 m interval)..... 23

Figure 9. Proportion of sites with bull trout present by stream order based on elevation classes (100 m interval). 24

Figure 10. Presence and absence of bull trout relative to elevation and temperature..... 24

Figure 11. Mean number of bull trout captured based on stream temperature. Error bars indicate 95% confidence intervals. 25

Figure 12. Relationship of each model β values for each parameter based on model type 30

Figure 13. The ROC plot for the best model (Habitat/GIS/Human disturbance) using logistic regression comparing results from all available data (full model) and average results from five random selections using 50% of the data (testing set). Numbers in parentheses are the areas under the curves..... 31

Figure 14. Relationship of the predicted probability of bull trout presence with percent timber harvest (a) and road density (b) calculated from the human disturbance model type, holding other attributes constant..... 31

Figure 15. Percentage of sites lost from four different simulated timber harvest levels in all watersheds where bull trout are present in the Kakwa River watershed. Each bar corresponds to a different density category. 33

Figure 16. Simulated bull trout distribution from 10% timber harvest scenario (all watersheds) 43

Figure 17. Simulated bull trout distribution from 25% timber harvest scenario (all watersheds) 43

Figure 18. Simulated bull trout distribution from 50% timber harvest scenario (all watersheds) 44

Figure 19. Simulated bull trout distribution from 75% timber harvest scenario (all watersheds) 44

Figure 20. Kakwa River watershed in northwestern Alberta..... 48

Figure 21. Ecoregions comprising the Kakwa River watershed..... 49

Figure 22. Distribution of bull trout density from 172 sites sampled in the Kakwa River basin. Density of trout represents the number of trout per 100 m of stream length. 53

Figure 23. Scatter plot of predicted probability of bull trout presence against the density of bull trout found at each sample site. Predicted presence is derived from the output of the resource selection function for the habitat/GIS model. 56

Figure 24. Corresponding levels of timber harvest associated with each density class (number of bull trout/100 m) in the Kakwa River watershed. 59

CHAPTER 1

GENERAL INTRODUCTION

Bull trout, (*Salvelinus confluentus*), declines throughout their historical range have been drastic (Brewin and Brewin 1997, Howell and Rieman 1997, Rieman and Myers 1997). The province of Alberta recently classified bull trout as a "sensitive" species (Alberta Sustainable Resource Development 2003). In 1990, the Committee on the Status of Endangered Wildlife in Canada, (COSEWIC), listed bull trout as "vulnerable" (Campbell 1990), whereas recently in the United States (1999), bull trout were recognized as a "threatened" species under the Endangered Species Act (MBTRT 2000). In Alberta, decreases in bull trout population abundance have been pronounced in the southern areas of the province, but declines in the northern portion have been less severe (Brewin and Brewin 1997). However, bull trout declines in northwestern Alberta have occurred. Anglers reported bull trout populations were in decline during the last 20 years, in contrast to Alberta populations further south that declined many years ago. This decline was brought about by a rapidly expanding access network developed by industry, as well as low flows, flooding, angling, land use (roads, timber harvesting) and improper installation of culverts (Walty and Smith 1997). Fitch (1997) further suggests that the decline in bull trout populations located in the southern portions of the province can be rapid, often occurring faster than resource managers or decision makers can react. Understanding the rate of change for individuals in a population is a key component of fisheries management (Paul 2000). In a natural ecosystem, given a population size of x individuals, fisheries management is faced with anticipating the number of individuals in

t years, and more importantly, whether influences from habitat loss or fragmentation play a role in shaping the future population. This may be achieved with predictive models for estimating populations and geographical ranges, and for identifying the potential impacts of habitat change (Fielding and Bell 1997).

Bull trout express three life history strategies in Alberta: resident populations that reside in the tributaries in which they were reared; fluvial populations which spawn in tributaries but reside in main stem rivers; and adfluvial populations that spawn in tributaries but reside in lakes or reservoirs (McCart 1997, Rieman and McIntyre 1993). They require complex habitats for spawning, rearing, wintering and migrating. They predominately reside in cold or cool waters where stream temperature does not exceed 18°C, typically at higher elevations. Bull trout tend to select areas that are well connected, structurally diverse and offer a buffering capacity for protection against high or low flow levels, substrate disruption, thermal loading and freezing and loss of pools and cover (Cross and Everest 1997).

Spawning typically occurs in second-to-fourth order streams although bull trout have been documented using fifth-order tributaries (Hvenegaard and Fairless 1998). Spawning areas are commonly selected where there is abundant cover and ground water influence. The association with ground water discharge is related to the stability of flows and temperature, important for incubating eggs (Baxter and Hauer 2000, Baxter and McPhail 1999). Egg incubation is long, with emergence of young-of-the-year in late April or early May, during which time they are extremely vulnerable to added deposition

of fine sediments or fluctuations in stream discharge. Juveniles rear in natal streams for 3 to 4 years before migration to the main-stem river/lake or remain in their natal stream if a resident life history is adopted. Adult maturity is late, usually at 5 to 7 years of age, suggesting implications for persistence when populations become exploited (Post and Paul 2000). Watershed size and stream width both appear to be important in lessening the risks of population declines (Rieman and McIntyre 1995). The complexity of habitat requirements for bull trout suggests that populations might be susceptible to human activities on the landscape. Activities such as industrial development, mining, road construction and timber harvest all might decrease the stability of bull trout habitat and decrease its complexity (McCart 1997, MBTSG 1998). Further habitat loss might result in an acceleration of extinction rates (Rieman *et al.* 1997, Rieman and McIntyre 1993).

The Kakwa River drainage supports two of the three life history forms, resident and fluvial, which coexist. The interaction between the two life history strategies remains unknown. However, given the importance of complex habitats, this implies spatial geometry (size, number and distribution) of suitable habitat matters to the dynamics and long-term persistence of these species' populations (Rieman and McIntyre 1993, Rieman and Dunham 2000). The Kakwa River bull trout population consists of the fluvial life history form entering into smaller tributaries to provide genetic exchange and offspring to maintain both resident and fluvial populations (for a complete review, see McCart 1997). Size of spawning habitats may be positively related to population persistence because larger habitats may support larger populations (Dunham and Rieman 1999). Relationships between variability in watershed quality (e.g., size, carrying

capacity, and productivity) and dispersal are key elements determining the structure and dynamics of bull trout populations.

PURPOSE AND OBJECTIVES

The focus of this thesis was to examine bull trout use in the Kakwa River watershed. My first objective was to describe the present distribution of bull trout across the watershed (Chapter 2). I evaluate this distribution using resource selection functions to determine habitat types or land use activities that are important in describing the present population distribution (Manly *et al.* 2002). I extend my research to evaluate the responses of bull trout to simulated scenarios altering the levels of land use activities. Based upon the occurrence models in Chapter 2, I link the abundance of bull trout to those models and attempt to evaluate the responses of bull trout density to various land management decisions and intensities (Chapter 3). Chapter 4 presents general conclusions and management implications for bull trout in the Kakwa River watershed.

LITERATURE CITED

Alberta Sustainable Resource Development. 2003. The general status of Alberta wild species 2000. Available online at:http://www3.gov.ab.ca/srd/fw/status/index.html

Baxter, C.V. and F.R. Hauer. 2000. Geomorphology, hyporheic exchange and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1470-1481.

Baxter, C.V. and J.D. McPhail. 1999. The influence of redd site selection, groundwater upwelling and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Zoology 77: 1233-1239.

Brewin, P.A. and M.K. Brewin. 1997. Distribution maps for bull trout in Alberta. Pages 209-216 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Campbell, R.R. 1990. COSEWIC status reports. Canadian Field Naturalist. 104:1-6.

Cross, D. and L. Everest. 1997. Fish habitat attributes of reference and managed watersheds, with special reference to the location of bull trout (Salvelinus confluentus) spawning sites in the upper Spokane River ecosystem, northern Idaho. Pages 381-386 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Dunham, J.B. and B.E. Rieman. 1999. Metapopulation structure of bull trout: Influences of physical, biotic and geometrical landscape characteristics. Ecological Applications 9: 642-655.

Fielding, A.H. and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24(1): 38-49.

Fitch, L.A. 1997. Bull trout in Southwestern Alberta: Notes on historical and current distribution. Pages 147-160 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Howell, P.J. and B. Rieman. 1997. Conservation of bull trout: Theory and applications. Page 448 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Hvenegaard, P.J. and D. Fairless. 1998. Biology and status of bull trout (*Salvelinus confluentus*) in the Kakwa River drainage, Alberta. A fisheries management enhancement project, Alberta Conservation Association. Data summary 1995 to 1997 Progress Reports. Alberta Conservation Association, Northwest Boreal Region, Peace River, AB. 30 p.

Manly, B.F., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: Statistical design and analysis for field studies. Second ed. Kluwer Academic Publishers, Dordrecht, The Netherlands. 221 p.

MBTRT (Montana Bull Trout Restoration Team). 2000. Restoration plan for bull trout in the Clark Fork River basin and Kootenai River basin Montana. Montana Bull Trout Restoration Team, c/o Montana Department of Fish, Wildlife and Parks, Helena, Montana. XII + 114p.

MBTSG (Montana Bull Trout Scientific Group). 1998. The relationship between land management activities and habitat requirements of bull trout. Unpubl. Rpt. Prepared for The Montana Bull Trout Restoration Team. Montana Department of Fish, Wildlife and Parks, Helena, Montana. 78p.

McCart, P. 1997. Bull trout in Alberta: a review. Pages 191-208 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Paul, A.J. 2000. Recruitment dynamics in bull trout (*Salvelinus confluentus*): Linking theory and data to species management. Ph.D. Thesis, Dept. of Biological Sciences, University of Calgary, Alberta.

Post, J.R. and A.J. Paul. 2000. A quantitative assessment of the recovery of bull trout populations in Alberta and development of models of sustainable yield. University of Calgary, Calgary, AB. Prepared for the Alberta Conservation Association. Section 6 p. 180-220.

Rieman B.E. and J.B. Dunham. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9: 51-64.

Rieman, B.E. and J.D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Forest Service General Technical Report INT-302.

Rieman, B.E. and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. 124: 285 – 296.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17:1111 – 1125.

Rieman, B.E. and D.L. Myers. 1997. Use of redd counts to detect trends in bull trout (*Salvelinus confluentus*) populations. Conservation Biology 11(4):1015-1018.

Walty, D.T. and D.R. Smith. 1997. Incorporating local knowledge into bull trout management in northwestern Alberta. Pages 187-190 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

CHAPTER 2

EVALUATING BULL TROUT (*Salvelinus confluentus*) DISTRIBUTION USING RESOURCE SELECTION FUNCTIONS

INTRODUCTION

The historical range of bull trout (*Salvelinus confluentus*) has been shrinking over the last decade (Howell and Rieman 1997, Brewin and Brewin 1997). This species requires complex habitat characteristics necessary for survival and reproduction (Post and Paul 2000, Rieman and McIntyre 1995, Baxter and McPhail 1999). Habitat requirements have placed some populations on the verge of extirpation in portions of its current range. The potential impact on fish habitat from human disturbances is well documented (MBTSG 1998, Fitch 1997). Understanding and developing management strategies to minimize anthropogenic disturbances is arguably the single largest challenge to sustainable resource development (Scrimgeour 2002, MacDonald 2000). Presently, management strategies set forth through provincial and federal legislation attempt to protect fisheries habitats; however, the complex interactions of anthropogenic disturbances is not well understood. In Alberta, a bull trout management and recovery plan focuses on two requirements: regulation and education (Ripley 2001, Berry 1994). This plan stipulates immediate measures to be taken including regulation changes, education on bull trout biology, communication of biological requirements to the public to provide a framework for a better understanding and the development of management plans specific for each area within the bull trout range. To maintain the plan, numerous other objectives have been suggested. These include collecting more information on bull trout life history, habitat requirements, interactions with land use activities and

determination of habitat conservation (Berry, 1994). In 1994, provincial regulations stipulated a province wide zero retention limit on bull trout. Within the Kakwa River watershed, a basin-wide catch and release regulation has been implemented and known-spawning tributaries closed to angling. In maintaining the bull trout management and recovery plan, numerous research programs have been conducted to better describe life history traits and habitat requirements critical for bull trout life processes. However, limited research has been conducted on the influence land use disturbances have on bull trout populations.

Expansion of Alberta's forest sector combined with conversion of forested lands to agriculture and increased oil and gas activities has raised concerns about the ecological sustainability of bull trout in northern Alberta. Activities of this nature may alter countless interrelated attributes of stream networks (Scrimgeour 2002). Understanding what effects timber harvest may have on bull trout distribution may offer land managers an improved understanding of consequences of land use decisions. Most importantly, how might these risks affect bull trout distribution, abundance and persistence, and what attributes play an important role in determining population decline or reduction in risk. Analysis of presence or absence of species populations are increasingly being used by fisheries biologists and land managers to identify the influence of anthropogenic factors on fish distribution and abundance (Mangel and Smith 1990, Scrimgeour 2002). Given the increase in access to large amounts of biodiversity information and the prevalence of geographic information systems (GIS), the capability of modelling and predicting species distribution is becoming more refined (Stockwell and Peterson 2002). Typically, the extent of habitat use by bull trout suggests the quality and abundance of resources at that

location is reflected by important covariates describing the habitat in the stream reach (Boyce and McDonald 1999). This suggests that where bull trout are present, we assume resources are being selected and used.

My examination is two-fold: First, I describe the distribution of bull trout across the Kakwa River watershed. Secondly, I attempt to determine whether the distribution of bull trout across the Kakwa River watershed is by random chance, or related to specific resources that explain their current distribution. I develop models to predict the occurrence (presence or absence) of bull trout populations in relation to stream attributes (reach scale), GIS variables (reach and watershed scale) and human disturbances (watershed scale). I use resource selection functions (RSF), defined as any model that yields values proportional to the probability of use of a resource unit, to evaluate this distribution of bull trout across the watershed (Boyce *et al.* 2002, Manly *et al.* 2002). The model is developed from observations of used and unused resource units. Combined with geographical information systems, RSF's are a powerful management tool in natural resource management, cumulative effects assessment, land management planning and population viability analysis (Boyce 1992, Boyce and McDonald 1999). To meet the above objectives, I use data collected from Government databases, Alberta Conservation Association and the Northern Watershed Program fisheries inventory programs. This information was useful in constructing candidate models using elements of physical habitat characteristics, GIS information and human disturbances. Considerable emphasis is placed on human disturbances, since these can be manipulated through adaptive management (Walters 1986).

STUDY AREA

The Kakwa River watershed is located along the eastern Rocky Mountains in northwestern Alberta and is part of the Peace River drainage (Figure 1). The watershed encompasses 3,475 km^2 and, in addition to bull trout, supports several native fishes including Arctic grayling (*Thymallus arcticus*), mountain whitefish (*Prosopium williamsoni*), numerous cyprinids as well as non-native rainbow trout (*Oncorhynchus mykiss,* Table 1). Bull trout are the predominate fish within the watershed and have been reported in most of the tributaries to the Kakwa River. The Kakwa River originates at Kakwa Lake (B.C.) and flows northeast across alpine, sub alpine and boreal cordillera ecoregions, converging with the Smoky River.

The majority of the basin is located within the sub alpine and upper and lower cordillera ecoregion (Figure 2). Vegetation is dominated by conifer over story comprised of lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*). Stream elevations range from 660 m ASL near the confluence with the Smoky River to above 1900-m ASL in the southwestern tributaries. Two sets of falls located on the Kakwa and South Kakwa rivers limit upstream migration. No bull trout have been documented above these falls. Bull trout remain in the watershed during all life stages and very few bull trout are known to migrate downstream out of the Kakwa River. Captured bull trout range in size from 45 to 731 mm fork length. Current industrial activities in the watershed include hydrocarbon extraction, seismograph exploration, road development and timber harvesting.

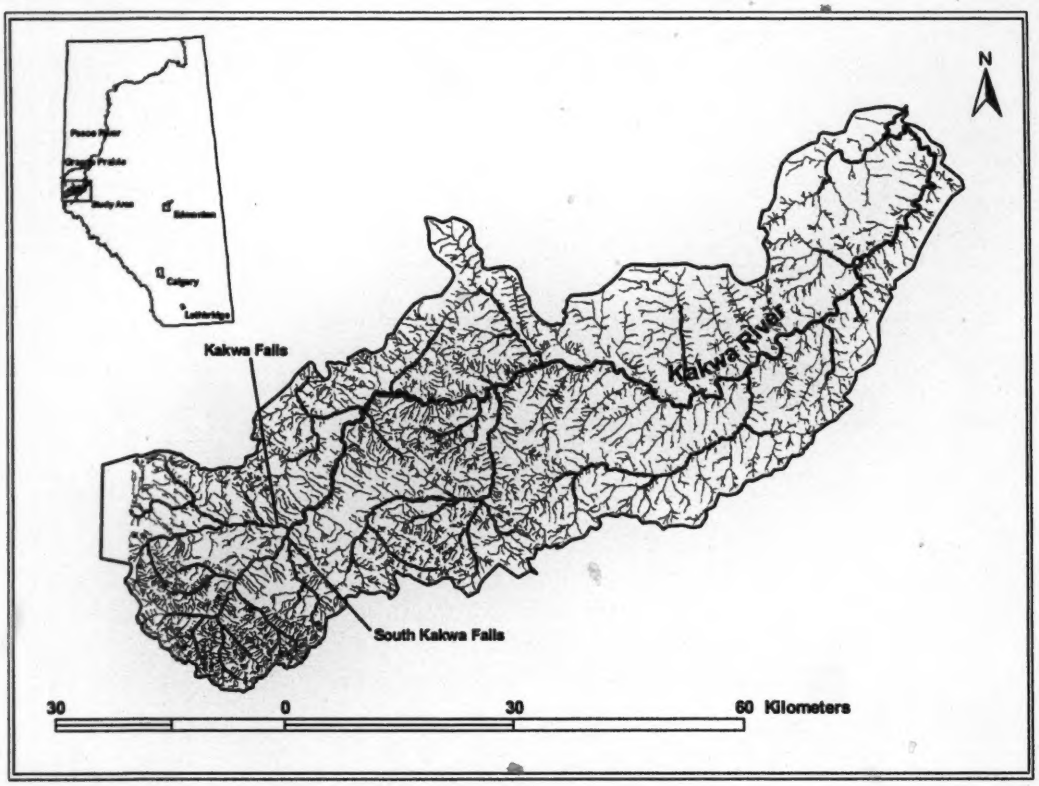

Figure 1. Kakwa River watershed in northwestern Alberta.

Table 1. Species distribution list in the Kakwa River watershed, in alphabetical order. * denotes game fish

Family	Common Name	Scientific Name
Catostomidae	Longnose sucker	*Catostomus catostomus* (Forster)
	White sucker	*Catostomus commersoni* (Lacepède)
Cottidae	Slimy sculpin	*Cottus cognatus* Richardson
Cyprinidae	Lake chub	*Couesius plumbeus* (Agassiz)
	Longnose dace	*Rhinichthys cataractae* (Valienciennes)
Gadidae	Burbot	*Lota lota* (Linnaeus)
Percidae	Walleye*	*Sander vitreus vitreus* (Mitchill)
Salmonidae	Arctic grayling*	*Thymallus arcticus* (Pallas)
	Bull trout*	*Salvelinus confluentus* (Suckley)
	Mountain whitefish*	*Prosopium williamsoni* (Girard)
	Rainbow trout*	*Oncorhynchus mykiss* (Walbaum)

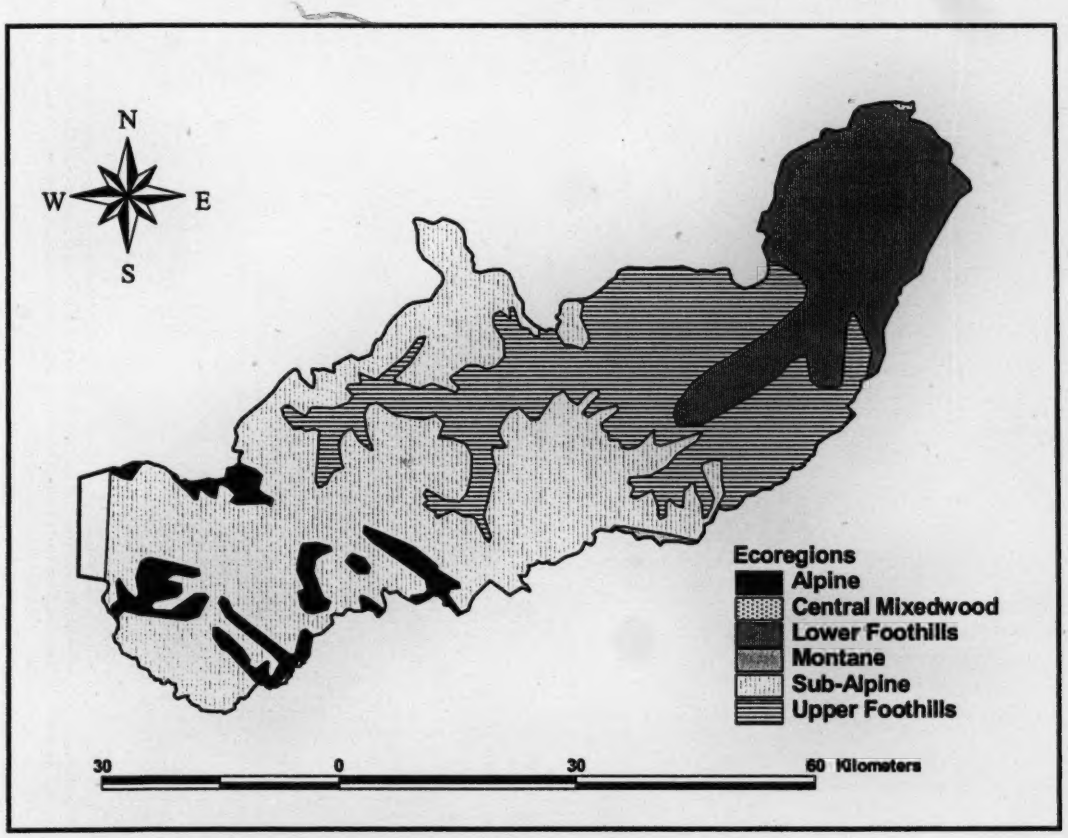

Figure 2. Ecoregions comprising the Kakwa River watershed.

METHODS

Field Collections

Bull Trout

Sampling was conducted from May to October of each year, after expected young-of-the-year bull trout emergence (Table 2). Sampling teams used a Smithroot™ Type 12 pulsed DC backpack electrofisher to capture trout and recorded distance (mean distance = 237 m) and effort in seconds (mean = 637 sec). All bull trout captured or observed were counted at each sample location. Sampling was conducted only when conductivity and water clarity were conducive to electrofishing success. Our sampling goal was to provide a reasonable probability of detecting bull trout and still allow for extensive sampling. A catch probability of 0.57 was determined from previous bull trout sampling in Lynx Creek (Hvenegaard, Unpubl data) and an estimate of abundance was calculated on the Kakwa River (estimate of 10 bull trout/km of stream, Tchir 2000). If we assume a poisson sampling distribution, the probability of detection should exceed 0.70. Thus, if the expected minimum number of bull trout detected was μ = (10 trout/1,000 m) × 237 m sampled × 0.57 and the probability of detecting no fish was $P(0) = e^{-\mu}$ (Zar 1999), then P(1 or more) = 0.74. Sample sites were selected at random, ensuring representation of all stream orders (1st through 6th) to make certain captures of bull trout were representative across the drainage (Figure 3). Stream orders, defined by Strahler (1964) are related to stream size. First-order streams are usually associated with headwater creeks. Second-order streams are defined when two first-order streams unite. Third-order streams are formed when two second order streams unite, and so on.

Table 2. Summary count of stream fish and habitat sample sites completed between 1994 and 2001. Sample sites are separated by stream order each year.

Year	Dates	Stream Order						Total
		1	2	3	4	5	6	
1994	Sep-Oct			5		1		6
1995	Jul-Sep	3	3	11	9	6	1	33
1996	Jul-Sep	1	1	13	10	4		29
1997	May-Oct	8	14	17	14	7	2	62
1998	May-Oct	1	4	13	11	5	4	38
1999	May-Aug				8	4	1	13
2000	Aug	7	13	20	20	3		63
2001	Aug	12	15	16	9	4		56
Total		32	50	95	81	34	8	300

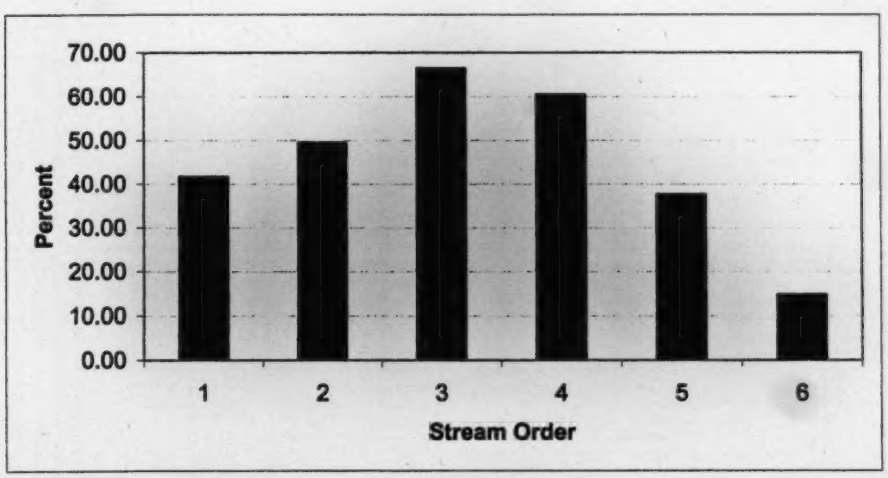

Figure 3. Proportion of sample sites represented by the proportion of each stream order by length. Therefore, 41% of sample sites were evaluated within the proportion of first order streams within the Kakwa River watershed.

Stream Attributes

Data on the physical attributes of stream reaches were collected at each site (Table 3). Sample site locations were geo-referenced using hand held GARMIN™ GPS units and referred to by UTM (Hvenegaard and Fairless 1998). All GIS data were entered into ArcView 3.1 and evaluated against Provincial inventory base

Table 3. Habitat variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed.

Variable	Abbreviation	Units
Water depth	Depth	Centimeters
Bankfull width	B_width	Meters
Wetted width	W_width	Meters
Fines	Fines	Percent
Small gravel	Sm_gravel	Percent
Large gravel	Lg_gravel	Percent
Cobble	Cobble	Percent
Boulder	Boulder	Percent
Bedrock	Bedrock	Percent
Temperature	Temp	Degrees celcius
Conductivity	Cond	MicroSiemens/cc
pH	pH	No units
Distance fished	Distance	Meters
Time fished	Time	Seconds

maps for UTM Zone 11. Sample sites were accessed from existing roads, trails and helicopter. Stream reaches were divided into 5 (1995-1997) or 3 (1998-2001) transects at equal distances along the stream length. Each transect was measured for depth, wetted width, bankfull width (high water mark) and substrate composition. Substrate composition was determined visually by estimating the percent cover of fines (<2 mm [silt/sand]), small gravel (2-16 mm), large gravels (17-64 mm), cobble (65-256 mm) and boulder (>256 mm). Wetted width (m) was measured from left to right bank covered in water at the time of the survey while bankfull width was the distance to the high water mark (discernable change in vegetation cover) across the stream channel. All stream attributes were averaged for each stream length and included in the analysis. Information from the DEM was delineated to each sample point.

Watershed Characteristics

All watershed characteristics were identified from GIS data layers (forest and road layers) and the DEM (Table 4). Elevation and slope were derived for each sample site. Stream slope was calculated from rise/run based on 100 m upstream and downstream of each sample location. Two groups of characteristics were identified: (1) watershed characteristics based on stream order and (2) portions of the watershed that directly contribute to a sample point. For example, a sample point located on a fourth order stream may be evaluated using the entire watershed attributes comprising the fourth order (4000 ha) or may only comprise that portion of the watershed above the sample point (2897 ha) that directly contribute to that sample site. The Alberta Vegetation Inventory (AVI) analysis provides watershed scale attributes such as timber harvest and linear road development and stream crossings. All attributes were deemed to describe bull trout habitats at each sample site. Human disturbance attributes were based on amount of forest cover removed compared to forested area in the watershed (percent watershed clear cut) and the density of linear disturbance of roads (km/km^2, Table 5).

Table 4. Watershed variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed.

Variable	Abbreviation	Units
Elevation	Elev	Meters
Stream slope	Str_slope	Rise/Run
Watershed area	Ws_ha	Hectares
Watershed slope	Ws_median	Rise/Run
Contributing watershed area	C_ha	Hectares
Contributing watershed slope	C_median	Rise/Run
Slope of riparian area within 100 meters of stream	R100_median	Rise/Run
Slope of riparian area within 300 meters of stream	R300_median	Rise/Run
Slope of riparian area within 500 meters of stream	R500_median	Rise/Run
Stream order	Str_ord	Strahler
Watershed area	Ws_km^2	Km^2

Table 5. Human disturbance variables collected and used to analyse relationship of bull trout presence and abundance within the Kakwa River watershed.

Variable	Abbreviation	Units
Watershed clear cut	P_watershed_cc	Percent
Watershed clear cut in last 10 yrs	P_watershed_cc10	Percent
Frequency of stream crossings from linear disturbance in watershed	Den_all_cross	Count/linear distance
Density of road crossings in watershed	Den_ws_rds	Count/road distance
Density of all roads in watershed	Den_rds_km	Km/km^2
Contributing watershed clear cut	P_c_cc	Percent
Contributing watershed clear cut in last 10 yrs	P_c_cc10	Percent
Density of contributing stream crossings from all linear disturbance in watershed	Den_c_cross	Count/linear distance
Frequency of contributing road crossings in watershed	Den_c_rds	Count/road distance
Frequency of contributing roads in watershed	Den_c_km	Km/km^2
Clear cut area within 300 meter radius of stream	R300_cc	Hectares
Clear cut area within 500 meter radius of stream	R500_cc	Hectares

STATISTICAL ANALYSIS

Model Development

Resource selection models can be constructed based on a comparison between used (presence) and unused (absence) samples of resource units (Manly *et al.* 2002). With an increased understanding of bull trout biology and habitat requirements (MBTSG 1998) we focused on building models based on ecological principles evaluated with data (Boyce *et al.* 2002). Models were constructed from attributes of physical habitat, GIS, human disturbance parameters and combinations of each. Before testing statistical evaluations, all data were screened for normality assumptions and for patterns of missing values and variance. Correlations among variables were evaluated prior to inclusion in models to avoid collinearity. I used logistic regression in SPSS (11.0) to determine

significant variables describing bull trout presence (or absence). Sites with bull trout present were assigned 1, while absent sites were assigned 0. The log-linear equation was assumed to characterize the influence of covariates on bull trout presence:

$$Logit(Y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_j x_j.$$

where β_0 is a constant and β_j are selection coefficients for each covariate x_j for j = 1,2...j. Negative β coefficients suggest an increase in the corresponding variable decreases the likelihood of bull trout being present, whereas a positive coefficient increases the probability of bull trout presence. When the resource selection model is correct, and the parameters are estimated by maximum likelihood, then the deviance of the model can be used as a measure of the goodness of fit (Manly *et al.* 2002). Deviance is defined as:

$$D = -2\{Log_e(L_M) - Log_e(L_F)\}$$

where L_M is the maximum likelihood of the fitted model and L_F ($\geq L_M$) is the likelihood for the model fitting the data perfectly. In this instance, the deviance is used for testing the goodness of fit of our model by comparing its value with the chi square distribution. If this is not significantly large then my model is considered reasonable.

Model Selection and Validation

I based selection of models on Akaike's Information Criteria (AIC) based on the significance of the likelihood of the model (Burnham and Anderson 1998, Anderson *et al.* 2000). AIC was calculated by adding 2*K* to the –2 log-likelihood value calculated from the regression where *K* is the number of parameters used in the model. This information criteria helps to identify the model that accounts for the most variation with the fewest number of variables and is one of the more powerful approaches to model

selection (Boyce *et al.* 2002). In this sense, models with many parameters are penalised. Each candidate model was evaluated by the difference in AIC values from the best model (Δ_i) and the Akaike weights (ω_i) given to those models from the equation:

$$\omega_i = \frac{\exp(-0.5 \times \Delta_i)}{\sum_{r=1}^{R} \exp(-0.5 \times \Delta_i)}$$

Once the best model was determined, I tested the discrimination capacity of the models using the receiver-operating characteristic (ROC). ROC was chosen over the use of traditional classification tables because of the ability of the ROC to analyse the proportion of correctly and incorrectly classified predictions over a continuous range of threshold probability cut-off levels (Fielding and Bell 1997, Boyce *et al.* 2002). The ROC plots the true positive fraction (sensitivity) against their equivalent false positive fraction (1-specificity). The value from the area under the curve (AUC) is between 0.5 and 1.0, where values approaching 1.0 indicates a better predictive model and a value of 0.5 describes a model with no predictive power (Fielding and Bell 1997). AUC values between 0.5 and 0.7 indicate poor discrimination, values of 0.7 to 0.9 provide reasonable discrimination ability and values greater than 0.9 have very good discrimination (Pearce and Ferrier 2000). The area under the curve from the ROC was used to validate each model by testing the values from the full model with that from the model calculated when fifty percent of the data was withheld (5 replicates). Top three candidate models for habitat, GIS and human disturbance parameters were selected to identify attributes relating to bull trout occurrence. The best performing model was used to simulate occurrence of bull trout over a range of human disturbance levels.

RESULTS

Bull Trout Distribution

In total, 300 sites were sampled between 1994 and 2001 in the Kakwa River basin (Figure 4). The sampling scheme represented all stream orders ranging from 1 through 6 (Figure 5). Bull trout were present in 46% of the sites (N=138) and dominated catches in 3rd and 4th order streams (74%). Bull trout catches at each site ranged from 0 to 75 with the highest number of catches noted in 4th, 3rd and 5th order streams respectively (Figure 6).

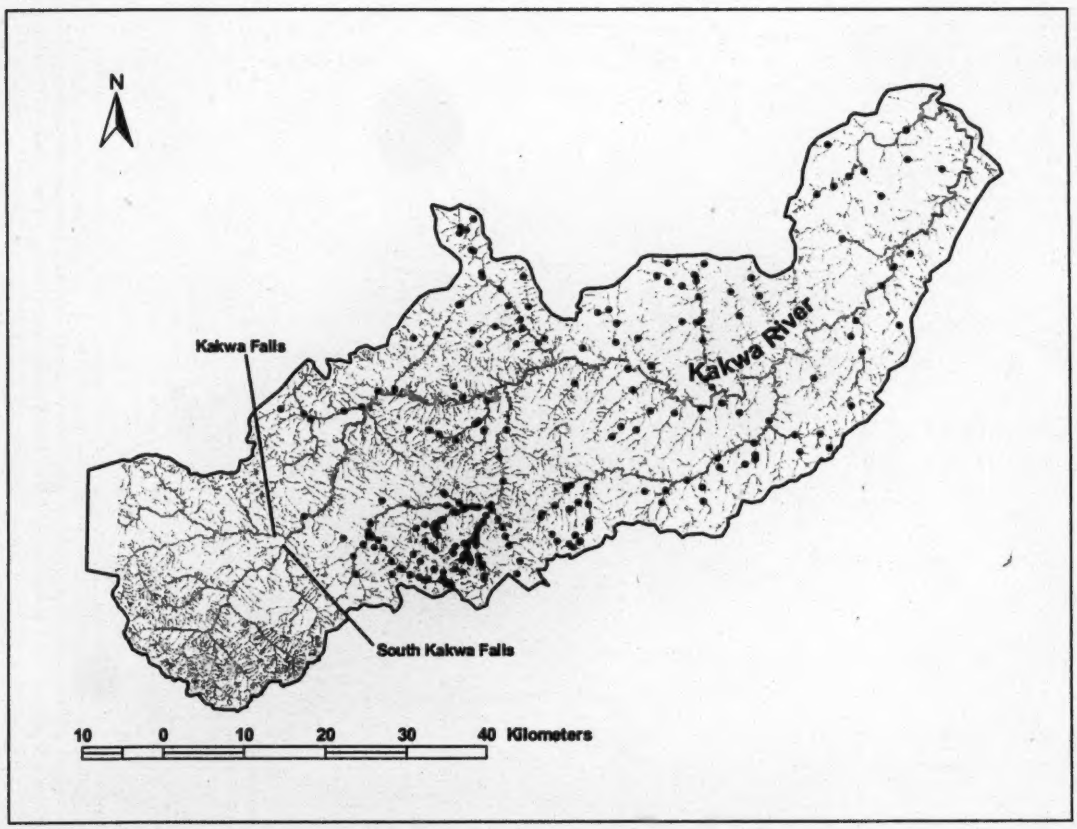

Figure 4. Distribution of sample sites (n=300) across the Kakwa River drainage

Sample site elevations ranged from 760 m to 1965 m (mean = 1303 m) above sea level. Numerically, the majority of bull trout were captured between 1300 and 1400 m (Figure 7) but catches per site indicate elevation range from 1500-1600 m dominated collection (Figure 8), all in 4th order streams (Figure 9). Water temperatures ranged from 1 to 19°C (mean = 9.7°C). Temperatures at the time of sampling were not strongly

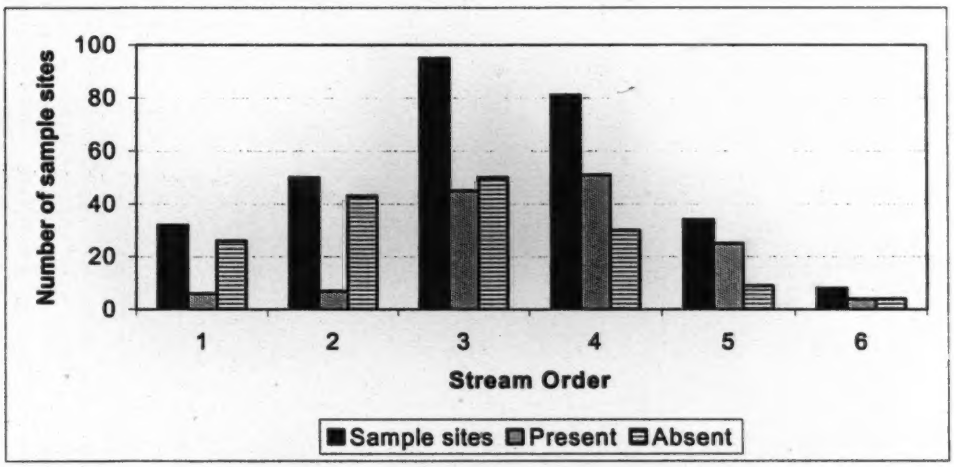

Figure 5. Distribution of sample sites by stream order within the Kakwa River watershed

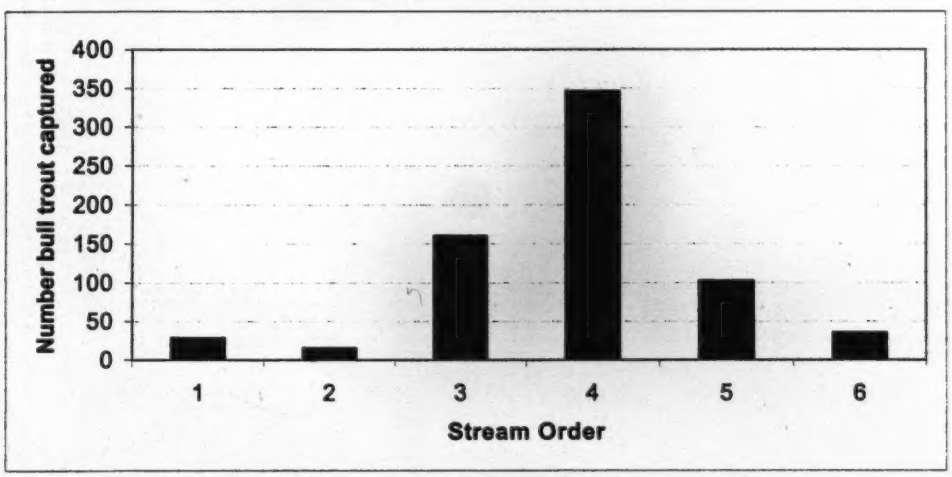

Figure 6. Description of bull trout captures by stream order in the Kakwa River watershed

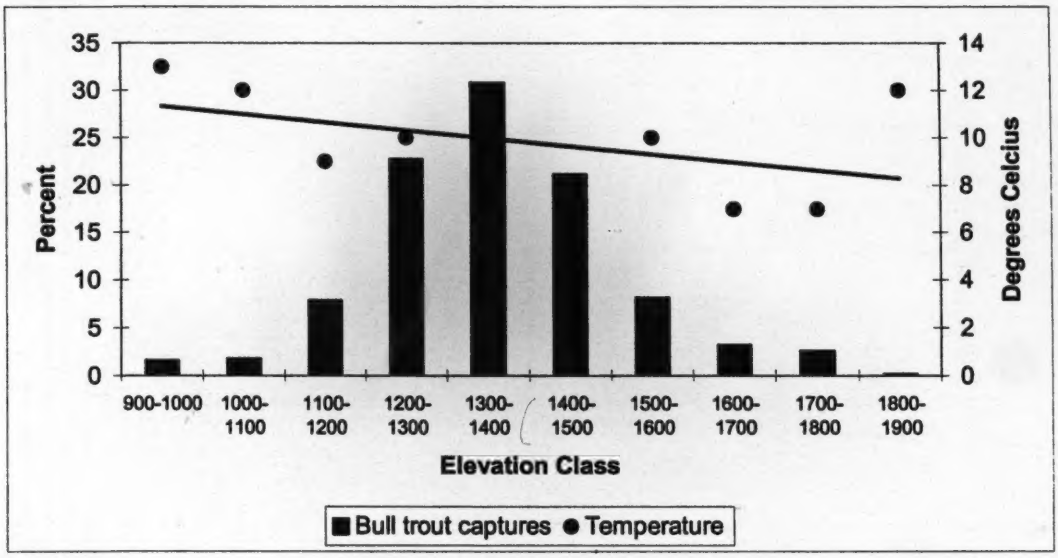

Figure 7. Percent of bull trout captures and water temperatures based on elevation classes (100 m interval)

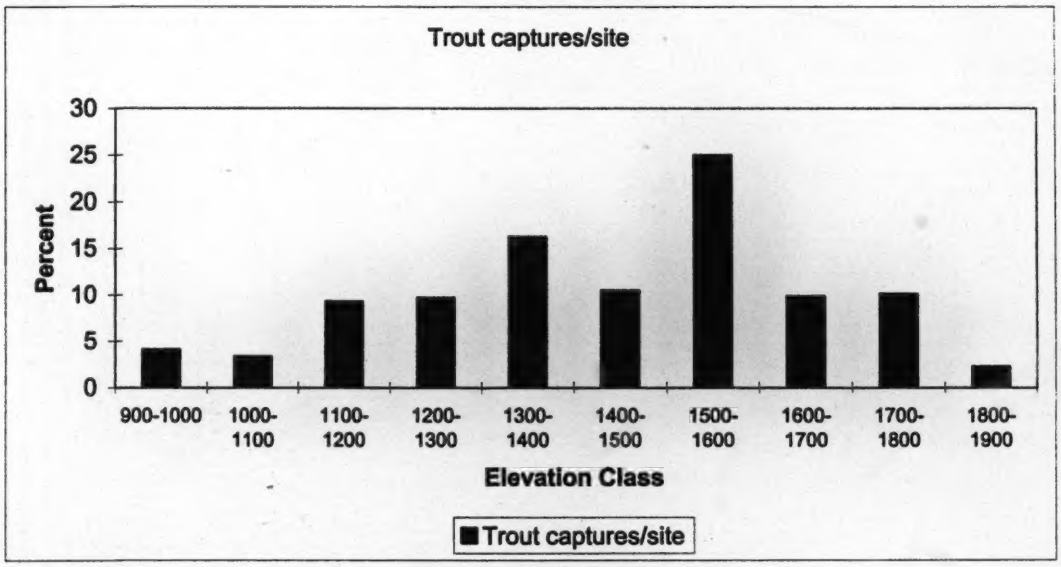

Figure 8. Bull trout captures by site based on elevation classes (100 m interval)

correlated with elevation (–0.267) although temperatures were significantly colder at higher elevations ($p<0.001$, Figure 10). More absent sites were found in lower elevations and at colder temperatures (<5°C). Highest catches were in stream reaches where temperatures were 11°C (Figure 11). The majority of bull trout were in stream reaches where water temperatures were between 7°C and 12°C (71%).

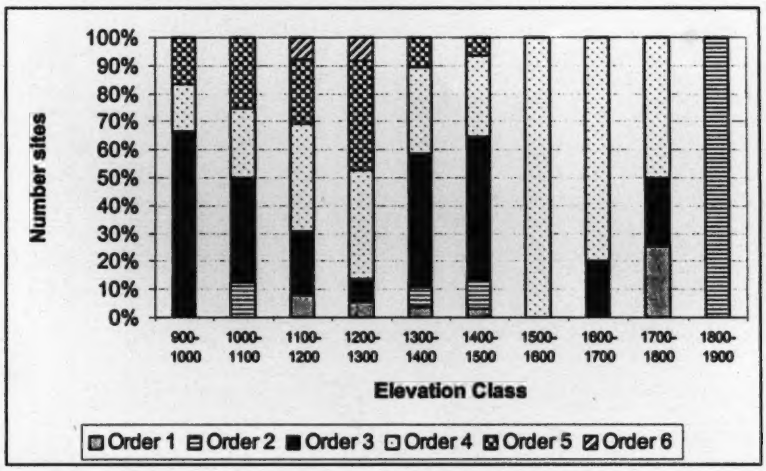

Figure 9. Proportion of sites with bull trout present by stream order based on elevation classes (100 m interval).

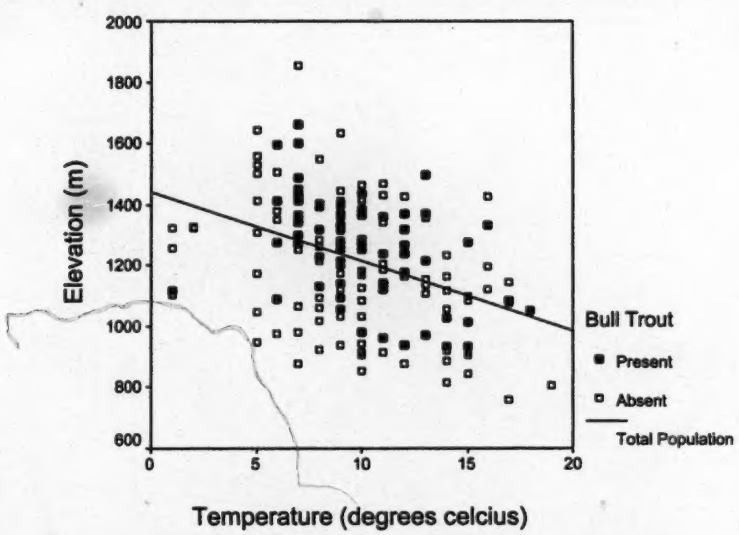

Figure 10. Presence and absence of bull trout relative to elevation and temperature.

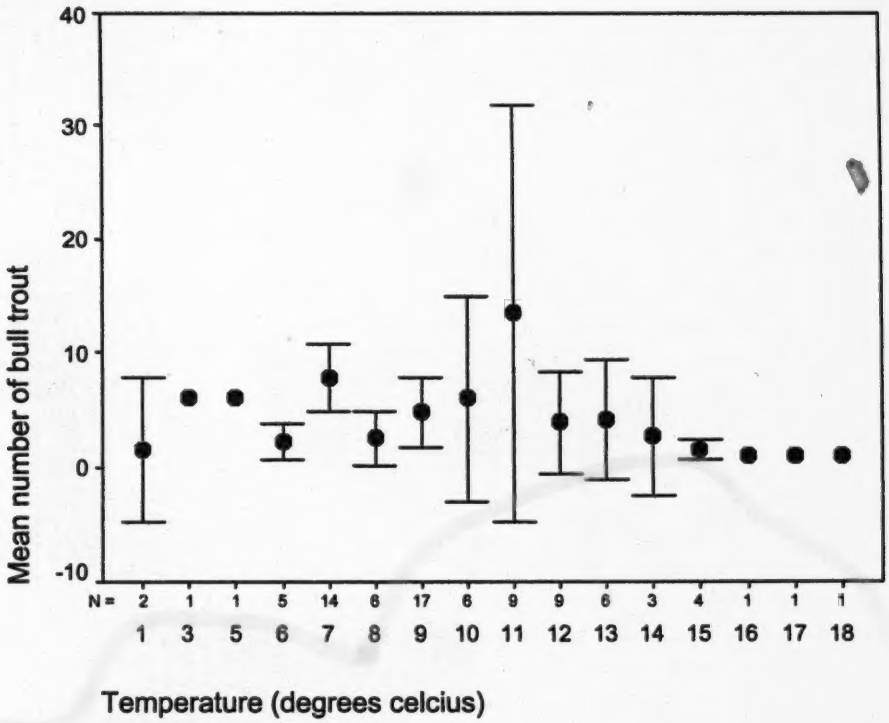

Figure 11. Mean number of bull trout captured based on stream temperature. Error bars indicate 95% confidence intervals.

Occurrence Models

Prior to model development, the data were screened to ensure duplicate stream reaches, sites visited on more than one occasion or sites that lacked all parameters used to evaluate bull trout presence were excluded from the analysis. Data screening resulted in the elimination of 128 sites. The remaining 172 sample points did not differ in the distribution based on stream order ($p<0.05$). All results further describing bull trout presence and absence in each model are based on the remaining 172 sample points (post screening).

Habitat models

The top three candidate models using habitat type variables are shown in Table 6. Stream width (bankfull), time and distance spent fishing was generally poor in describing bull trout occurrence. The amount of fine sediment alone had reasonable capability of discriminating occurrence, however, when combined with bankfull width, presence of bull trout was at least 13 times more likely to explain occurrence than use of fine sediment alone. The best model was developed combining bankfull width (positive relationship to presence) and average level of fine sediment (negative relationship), having the lowest AIC score and highest weighted AIC ($\omega_i = 0.93$). The best model had an ROC value of 0.737.

Table 6. Candidate models describing bull trout presence and absence using habitat attributes (Table 3). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models.

Model Type	Variable	β	S.E.	D^2	Δ_i	ω_i	ROC
Habitat	Fines	-0.045	0.014	16.5	0.00	0.930	0.737
	B_width	+0.059	0.024				
	Fines	-0.050	0.013	12.9	5.2	0.069	0.694
	B_width	+0.056	0.029				
	Time	+0.000	0.000	10.9	13.29	0.001	0.715
	Distance	+0.005	0.002				

GIS models

Stream order and elevation were important variables in all three of the top candidate models (Table 7). Elevation and stream order were not correlated (-0.052). Both parameters had a positive relationship with bull trout presence. The best model (lowest AIC) explained less deviance and had a lower ROC value, but was chosen since the model with added parameters is penalized in model selection using AIC. The ROC

value for the top model was 0.793; however all models were similar in determining occurrence. Inclusion of the parameters for watershed area (km^2) and the perpendicular slope of the riparian area adjacent to the stream (500 m) did improve the ROC and explained slightly more deviance. Based on the weighted AIC scores, all three models did not appear to show large differences in their explanatory capability.

Table 7. Candidate models describing bull trout presence and absence using GIS attributes (Table 4). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models.

Model Type	Variable	β	S.E.	D^2	Δ_i	ω_i	ROC
GIS	Str_ord	+1.047	0.188	24.5	0.00	0.445	0.793
	Elev	+0.003	0.001				
	Ws_km^2	-0.005	0.004	25.3	0.28	0.387	0.799
	Str_ord	+1.228	0.239				
	Elev	+0.003	0.001				
	Ws_km^2	-0.005	0.004	25.5	1.94	0.169	0.801
	Str_ord	+1.170	0.257				
	Elev	+0.002	0.001				
	R500_median	+1.627	2.840				

Human Disturbance models

The percent of the watershed harvested and the density of contributing roads within the watershed were included in all candidate models (Table 8). Both variables had a large negative coefficient when independently compared to habitat and GIS models. Contributing road density and crossing density (accounting for roads and stream crossings that contribute to the sample site) explained slightly more deviance than those same parameters that take into account the entire watershed where the sample was taken. Overall the model ROC's ranged from 0.726-0.750.

Table 8. Candidate models describing bull trout presence and absence using human disturbance attributes (Table 5). β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models.

Model Type	Variable	β	S.E.	D^2	Δ_i	ω_i	ROC
Human disturbance	P_watershed_CC	-5.260	1.568	15.9	0.00	0.450	0.726
	Den_c_km	-1.967	0.890				
	Den_c_cross	+0.216	0.181	16.6	0.49	0.389	0.748
	Den_c_km	-0.206	0.905				
	P_watershed_CC	-5.305	1.567				
	Den_all_cross	+0.349	0.224	15.4	2.93	0.115	0.750
	Den_c_km	-1.742	1.002				
	P_watershed_CC	-5.687	1.583				

Model Combinations

Models developed using physical habitat, GIS and human disturbance attributes individually did poorly in predicting presence and absence of bull trout overall. The best model comprised variables from a combination of model types (Table 9). This model included attributes for average percentage of fine sediment, stream order and the percent of timber harvest in watersheds where samples were collected (Habitat/GIS/ Human disturbance model). This model explained 30% of the deviance and had the lowest AIC score. Alternative models incorporating reach distance fished and site elevation (Habitat/GIS model, $\omega_i = 0.38$) and road density (GIS/human disturbance model $\omega_i = 0.15$) were closely related. In each model type, negative β values were calculated from percent of fines, timber harvest and road density (Figure 12). Area under the curve values from the ROC were calculated for the best models and tested by withholding 50% of the data (testing set) pooled from 5 random site selections (Table 10).

Table 9. Candidate models describing bull trout presence and absence. Each model type incorporates respective attributes based on physical habitat, GIS and human disturbance parameters. β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models.

Model Type	Variable	β	S.E.	D^2	Δ_i	ω_i	ROC
Habitat Only	Fines	-0.045	0.014	16.5	23.99	0.00	0.737
	B_width	+0.059	0.017				
GIS Only	Str_ord	+1.047	0.000	24.5	8.07	0.01	0.793
	Elev	+0.003	0.002				
Human Disturbance	P_watershed_CC	-5.260	0.001	15.9	25.29	0.00	0.726
	Den_c_km	-1.967	0.027				
Habitat/GIS	Str_ord	+0.721	0.207	30.3	0.41	0.38	0.830
	Fines	-0.027	0.014				
	Distance	+0.005	0.002				
	Elev	+0.003	0.001				
Habitat/ Human Disturbance	P_watershed_CC	-6.393	1.786	23.9	13.25	0.00	0.802
	Den_c_km	-1.682	0.978				
	B_width	+0.086	0.028				
	Den_all_cross	+0.359	0.232				
GIS/ Human Disturbance	P_watershed_CC	-4.671	1.821	28.4	2.27	0.15	0.816
	Den_c_km	-1.506	1.043				
	Str_ord	+0.830	0.184				
Habitat/GIS/ Human Disturbance	Fines	-0.024	0.129	30.0	0.00	0.46	0.825
	P_watershed_CC	-5.405	1.684				
	Str_ord	+0.737	0.193				

For each model type, the ROC had a reasonable discriminatory capability both when using the full model and the testing dataset (Figure 13).

Predicted probabilities of bull trout presence were calculated from resource selection functions (w_x) for the best model. This selection was based on the logistic regression model with probabilities determined from the equation:

$$w_x = \frac{\exp(\beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p)}{1 + \exp(\beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p)}$$

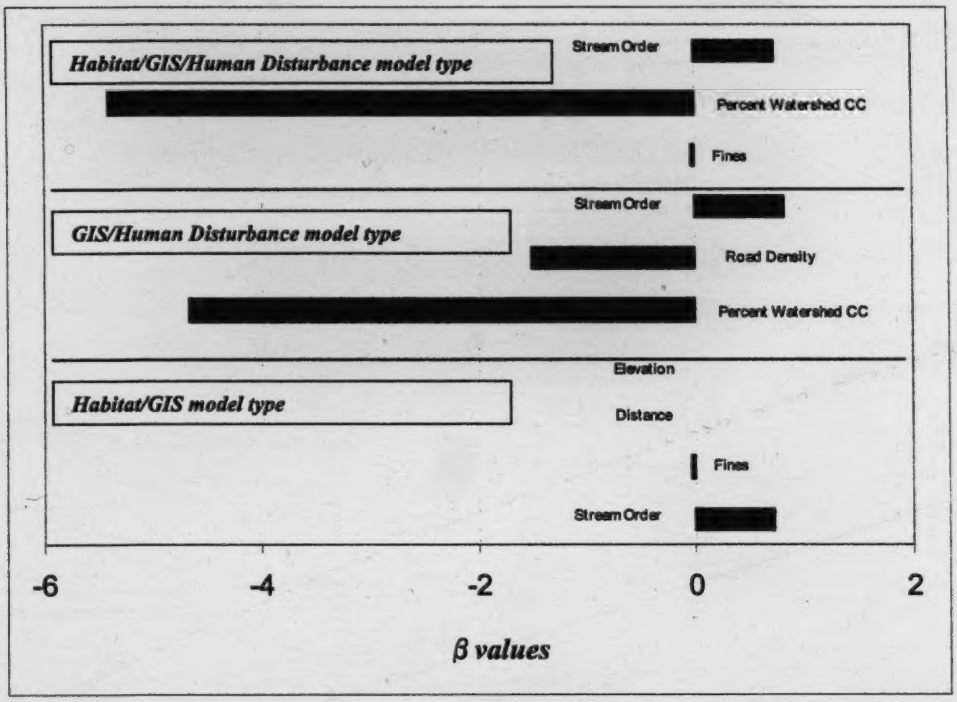

Figure 12. Relationship of each model β values for each parameter based on model type

Table 10. Comparison of ROC results and standard error from the three best models predicting bull trout distribution. Full model incorporates all data. Test model is the mean of five replicates for each model type calculated from randomly withheld data (50%).

Model Type	Model	ROC score	S.E.
Habitat/GIS/Human disturbance	Full	0.825	0.031
	Test	0.809	0.046
Habitat/GIS	Full	0.830	0.031
	Test	0.815	0.046
GIS/Human disturbance	Full	0.816	0.032
	Test	0.793	0.049

Two human disturbance attributes from the logistic model prominently contributed to bull trout presence. In each case, predicted presence dropped considerably with an increase in both the level of timber harvest and road density, all other attributes held constant (Figure 14).

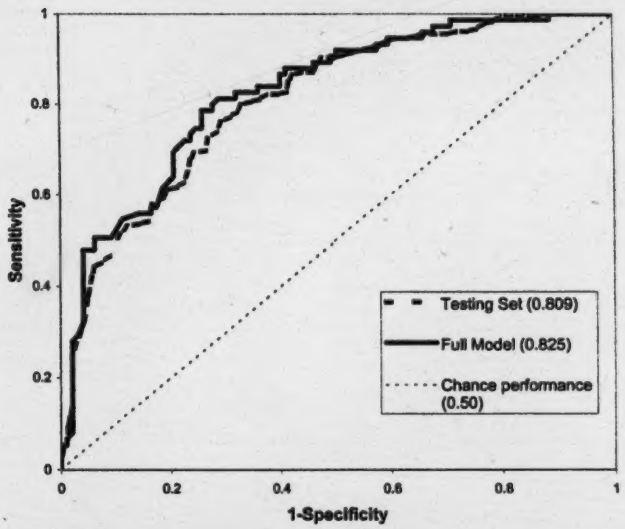

Figure 13. The ROC plot for the best model (Habitat/GIS/Human disturbance) using logistic regression comparing results from all available data (full model) and average results from five random selections using 50% of the data (testing set). Numbers in parentheses are the areas under the curves.

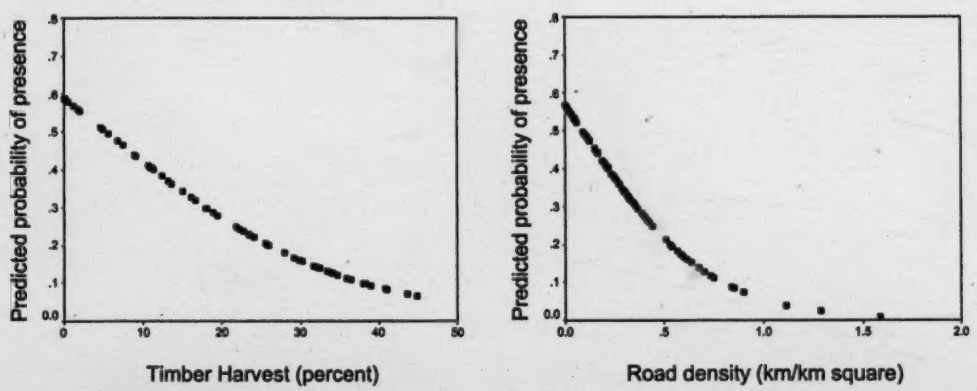

Figure 14. Relationship of the predicted probability of bull trout presence with percent timber harvest (a) and road density (b) calculated from the human disturbance model type, holding other attributes constant.

To evaluate various land management decisions, timber harvest levels were artificially inflated in presently logged basins and all basins equally across the Kakwa River watershed. I assume that all simulated levels of timber harvest would occur over a very short time period, similar to the collections from this research. Timber harvesting

levels were elevated by 10%, 25%, 50% and 75%. The model coefficients for levels of fine sediment and stream order were held at their appropriate level. Simulated increases of 10% in all watersheds (21, 627 ha) and all currently harvested watersheds with bull trout present (1681 ha) results in losses of 24% and 20% of bull trout sites, respectively (Table 11). At extreme harvesting levels, it is predicted that 60% of the sites presently containing bull trout would be lost. Spatial representation of bull trout site losses is included in Appendix 1.

Table 11. Response of sites presently with bull trout to simulated increases of timber harvest in the entire basin (all watersheds) and basins already harvested (harvested watersheds).

Level of simulated timber harvest increase	All watersheds		Harvested watersheds	
	Total sites lost	Cumulative total	Total sites lost	Cumulative total
10%	18 (24%)	18 (24%)	15 (20%)	15 (20%)
25%	6 (8%)	24 (32%)	3 (4%)	18 (24%)
50%	13 (17%)	37 (51%)	0 (0%)	18 (24%)
75%	8 (11%)	45 (60%)	4 (5%)	22 (29%)

Average density (number/100 m of stream) ranged from 0 to 19.1 bull trout where they were found present. I evaluated the simulations based on a range of density classes from low (0-1) to high (>5). Models runs show that low-density sites (0-1 and 1-2 trout/100 m) are lost first as timber harvest increases (Figure 15). High-density sites begin to be lost once simulated timber harvest reaches 50% and only reach a maximum of 33% lost.

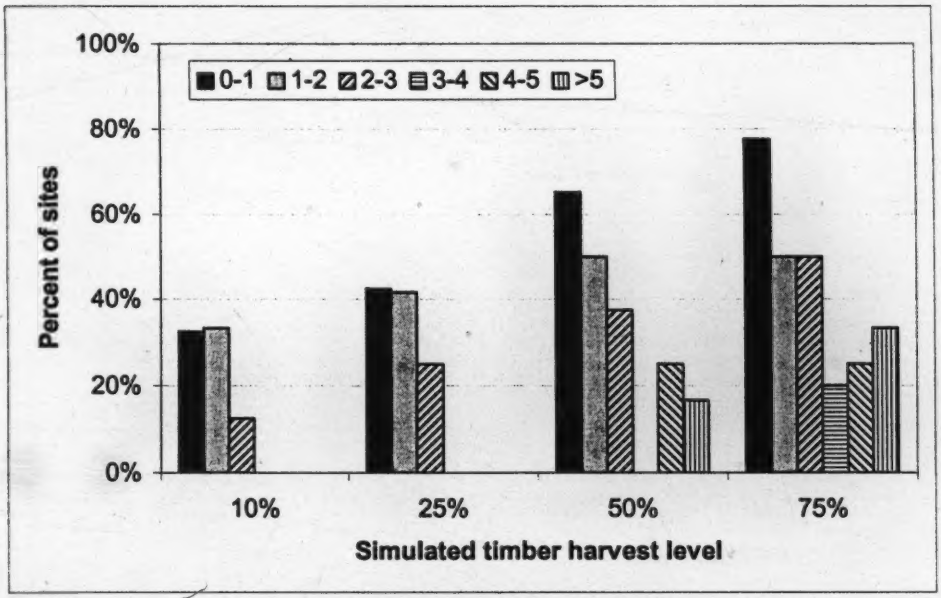

Figure 15. Percentage of sites lost from four different simulated timber harvest levels in all watersheds where bull trout are present in the Kakwa River watershed. Each bar corresponds to a different density category.

DISCUSSION

My focus was to investigate responses of bull trout occurrence built on models evaluating various parameters. This discussion focuses primarily on human disturbance variables, which can be manipulated based upon a suite of land management decisions or alternative strategies. Therefore, it is useful to understand the attributes that will affect this new distribution and determine how much of a role they play in bull trout responses. I evaluate effective predictive models that represent key features in aquatic ecosystems. The use of predictive models is important in the assessment of environmental concerns and for testing scientific fundamentals (Pace 2001).

When identifying non-anthropogenic attributes, stream size and elevation are primary factors determining bull trout distribution in this drainage. Similar findings have been noted in other drainages, for bull trout specifically (Watson and Hillman 1997, Rieman and McIntyre 1995, Baxter *et al.* 1999, Rieman *et al.* 1997) and for other species in general (Bayley and Peterson 2001, Paul and Post 2001). Evaluation of habitat models also shows the amount of fine sediment and average bank full widths of the stream were overwhelmingly the best predictors describing bull trout presence in the Kakwa watershed. Bull trout were more likely to be detected where streams were larger and had fewer fine sediments. Fine sediment deposition increased in sites where timber harvesting occurred compared to areas without any timber harvest. Watson and Hillman (1997) reported not only surface sediments, but sediment depth had a negative effect on bull trout distribution. Overall, habitat-only variables were poor in describing bull trout presence and absence when compared to all other candidate models evaluated.

GIS variables are attractive to land-use managers because all variables can be gathered from DEM's without the requirement of field surveys. The model incorporating stream order and elevation was the best predictor of bull trout distribution. Other models incorporating watershed size (km^2) and mean slope of the riparian area within a 500 m radius of the sample site added very little explanation to the stream order and elevation model, but slightly improved the discriminatory capability (ROC). Increasing stream order (larger stream size) and higher elevations are consistent with other reports on influence of bull trout distribution in North America (Rieman and McIntyre 1995). Higher elevations resulted in reduced water temperatures, which was a prominent factor of bull trout abundance. Elevated temperature is considered an important factor in the decline of bull trout, having thermal tolerance limits of 20.9°C (Selong *et al.* 2001).

Fewer bull trout were expected to be found in higher elevation streams, primarily because these streams are typically smaller in size. However, while presence was related to increased stream size, it was also strongly correlated to elevation. Because of the presumed restriction of bull trout populations by water temperature, Rieman and McIntyre (1995) define watersheds above 1600 m as potential bull trout habitat. My findings suggest that while bull trout presence is related to temperature, highest catches were predominately below 1600 m, with the majority of trout captured in elevations between 1300 and 1600 m, where water temperatures ranged from 1 to 16°C (mean = 8.5°C). The majority of timber harvest has been in areas with elevations less than 1200 m (90%). I evaluated presence of bull trout by separating data into two elevation classes, below and above 1200 m. It is evident that bull trout presence remained negatively

related to timber harvest levels at the lower elevations, suggesting decreased predicted occurrence is a response to timber harvest levels, rather than elevation alone.

Increased demand for renewable and non-renewable resources clearly will impact bull trout distribution in the Kakwa River watershed. However, use of human disturbance variables in isolation of other stream and watershed characteristics does not describe occurrence well in the Kakwa basin ($\Delta_i = 13.25$). However, in each instance, percent timber harvest and density of roads negatively predicted bull trout presence. Crossing density had a positive relationship with occurrence, which could likely be explained by fish pooling at crossing sites, particularily when they are impassable barriers to upstream movement (Warren and Pardew 1998). My findings support the statement that increasing levels of timber harvest have a negative impact on bull trout occurrence, as illustrated by the best logistic model, showing a positive relationship with stream order and negative relationship with fine sediment and timber harvest. Both stream size and elevation are natural features of aquatic systems, however presence of fine sediment may occur naturally or in response to some form of human disturbance. Elevated sediment levels can result from road construction, road approaches, or improperly installed stream crossing structures (Birtwell 1999, Eaglin and Hubert 1993, Reid and Dunne 1984). Direct and indirect links between timber harvest and occurrence of bull trout may be many. Research suggests the cumulative effect of logging and road development has an impact on landscape structure (McGarigal *et al.* 2001) and can influence fish distribution (Ziemer *et al.* 1991, Grant *et al.* 1986) and stream temperature (Teti 1998). Presently, timber harvest in the Kakwa River watershed is low, accounting for only 6.3% of the forested land base. Predicted decreases in bull trout presence from

increased timber harvest may be attributed to increased frequency of flooding events and subsequent increases in fine sediment deposition. Swanson and Hillman (1977) have reported annual water yield increases of 20-30% and peak storm flow increases 4-5 times higher than normal after clear-cut logging. Findings from the present research support these conclusions.

The road density variable also showed a strong negative relationship in the occurrence models. This variable was shown important in all three human disturbance candidate models in addition to the human disturbance-GIS model which was closely related to the best logistic model ($\Delta_i = 2.27$). Road density in the Kakwa watershed is low, less than 0.20 km/km^2. However, even at low levels, the model illustrates that increases in road density reduces predicted occurrence of bull trout. Road development and inevitable stream crossings may limit movement of bull trout and contribute fine sediment and debris to the stream from road surface or ditches. Warren and Pardew (1998) indicated culvert crossings reduced overall fish movement over a range of flows during spring and summer months. Late fall movements of bull trout to spawning areas may be difficult when low flows prevent fish passage. Baxter *et al.* (1999) reported road density increases as low as 0.1 km/km^2 show significant declines in bull trout spawning redds over time.

These results suggest that when timber harvest and road development in the Kakwa watershed increases, bull trout populations may be lost. Recognition of the potential spatial effects and site-specific responses will improve understanding of bull trout habitat suitability. The results identify a need for a more detailed approach to timber harvesting and road development in the watershed, and are a useful tool to build

upon when determining large-scale anthropogenic disturbances across the watershed. Bull trout can be seen as a surrogate for many other species in the Kakwa because of their need for complex and sometimes specific habitat requirements (i.e. groundwater). Therefore, using resource selection functions to build predictive models is very useful for fisheries managers, land-use planners and decision makers.

REFERENCES

Anderson, D.R., K.P. Burnham and W.L. Thompson. 2000. Null hypothesis testing: problems, prevalence and an alternative. Journal of Wildlife Management 50: 157-165.

Baxter, C.V., C.A. Frissell, and F.R. Hauer. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: Implications for management and conservation. Transactions of the American Fisheries Society 128: 854-867.

Baxter, C.V. and J.D. McPhail. 1999. The influence of redd site selection, groundwater upwelling and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Zoology 77: 1233-1239.

Bayley, P.B and J.T. Peterson. 2001. An approach to estimate probability of presence and richness of fish species. Transactions of the American Fisheries Society 130: 620-633.

Berry, D.K. 1994. Alberta's bull trout management and recovery plan. Unpublished report. Alberta Environmental Protection, Fish and Wildlife Service. Edmonton, AB.

Birtwell, I.K. 1999. The effects of sediment on fish and their habitat. Fisheries and Oceans Canada, Science Branch. Marine environment and habitat sciences division, freshwater environment and habitat sciences branch, West Vancouver, B.C.

Boyce, M.S. 1992. Population viability analysis. Annual Reviews of Ecology and Systematics 23: 481-506

Boyce, M.S. and L.L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology and Evolution 14: 268-272.

Boyce, M.S., P.R. Vernier, S.E. Nielson, and F.K.A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281-300

Brewin, P.A. and M.K. Brewin. 1997. Distribution maps for bull trout in Alberta. Pages 209-216 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Burnham, K.P. and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag: New York. 353 pp.

Eaglin, G.S. and W.A. Hubert. 1993. Effects of logging roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. North American Journal of Fisheries Management 13:844-846.

Fielding, A.H. and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24(1): 38-49.

Fitch, L.A. 1997. Bull trout in Southwestern Alberta: Notes on historical and current distribution. Pages 147-160 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Grant, J.W.A., J. Englert, and B.F. Bietz. 1986. Application for a method for assessing the impact of watershed practices: Effects of logging on salmonid standing crops. North American Journal of Fisheries Management 6: 24-31.

Howell, P.J. and B. Rieman. 1997. Conservation of bull trout: Theory and applications. Page 448 *in* Mackay, W.C., M.K. Brewin and M. Monita, editors. Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Hvenegaard, P.J. and D. Fairless. 1998. Biology and status of bull trout (*Salvelinus confluentus*) in the Kakwa River drainage, Alberta. A fisheries management enhancement project, Alberta Conservation Association. Data summary 1995 to 1997 Progress Reports. Alberta Conservation Association, Northwest Boreal Region, Peace River, AB. 30 p.

MacDonald, L.H. 2000. Evaluating and managing cumulative effects: Process and constraints. Environmental Management 26: 299-315.

Mangel, M., and P.E. Smith. 1990. Presence-Absence sampling for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 47: 1875-1887.

Manly, B.F., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: Statistical design and analysis for field studies. Second ed. Kluwer Academic Publishers, Dordrecht, The Netherlands. 221 p.

MBTSG (Montana Bull Trout Scientific Group). 1998. The relationship between land management activities and habitat requirements of bull trout. Unpubl. Rpt. Prepared for The Montana Bull Trout Restoration Team. Montana Department of Fish, Wildlife and Parks, Helena, Montana. 78p.

McGarigal, K., W.H. Romme, M. Crist, and E. Roworth. 2001. Cumulative effects of roads and logging on landscape structure in the San Juan mountains, Colorado (USA). Lanscape Ecology 16: 327-349.

Pace, M.L. 2001. Prediction and the aquatic sciences. Canadian Journal of Fisheries and Aquatic Sciences 58:63-72

Paul, A.J. and J.R. Post. 2001. Spatial distribution of native and nonnative salmonids in streams of the eastern slopes of the Canadian Rocky Mountains. Transactions of the American Fisheries Society 130:417-430.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133: 225-245.

Post, J.R. and A.J. Paul. 2000. A quantitative assessment of the recovery of bull trout populations in Alberta and development of models of sustainable yield. University of Calgary, Calgary, AB. Prepared for the Alberta Conservation Association. Section 6 p. 180-220.

Reid, L.M. and T Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20: 1753-1761.

Rieman, B.E. and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124: 285 – 296.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17: 1111-1125.

Ripley, T.D. 2001. Management of bull trout (Salvelinus confluentus) in the Kakwa River drainage: Where are we at, where are we going, and how are we going to get there? Pages 223-226 *in* M.K. Brewin and M. Monita, editors. Bull trout II Conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Scrimgeour G. 2002. Cumulative effects of watershed disturbances on stream fish communities in the Kakwa and Simonette river basins, Alberta. Unpubl. Report. Alberta Conservation Association and Alberta Research Council, Northern watershed program. 124 pp.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerances in fishes. Transactions of the American Fisheries Society 130: 1026-1037.

Stockwell, D.R.B., and A.T. Peterson. 2002. Effects of sample size on accuracy of species distribution models. Ecological Modelling 148: 1-13.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks; Section 4-2 in: Handbook of Applied Hydrology, Van Te Chow ed. McGraw-Hill, New York

Swanson, R.H. and G.R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Information report #NOR-X-198. Northern Forest Research Center, Canadian Forestry Service, Fisheries and Environment Canada, Edmonton, Alberta, Canada. 40 pp.

Tchir, J. 2000. Population estimates of the Kakwa River bull trout (*Salvelinus confluentus*) Fall 2000. Alberta Conservation Association, Northwest Boreal Region. 22 pp.

Teti, P. 1998. The effects of forest practices on stream temperature: A review of literature. B.C. Ministry of Forests, Williams Lake, B.C. 10 pp.

Walters, C.J. 1986. Adaptive management of renewable resources. Macmillan, New York

Warren, M.L. and M.G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127: 637-644

Watson, G. and T.W. Hillman. 1997. Factors affecting the distribution and abundance of bull trout: An investigation at hierarchical scales. North American Journal of Fisheries Management 17: 237-252.

Zar, J.H. 1999. Biostatistical Analysis Fourth Edition. Prentice-Hall, Upper Saddle River, New Jersey

Ziemer, R.R., J. Lewis, R.M. Rice, and T.E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. Journal of Environmental Quality 20: 36-42.

APPENDIX 1

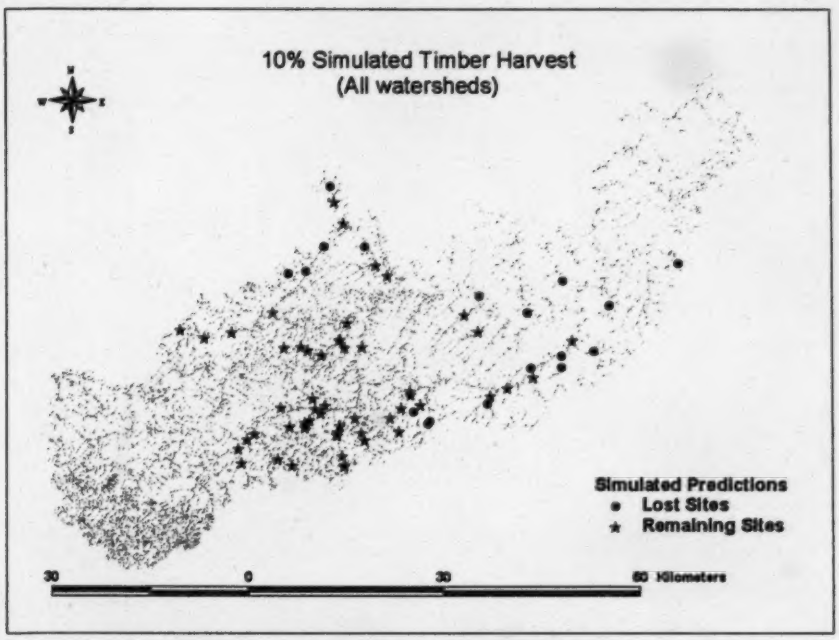

Figure 16. Simulated bull trout distribution from 10% timber harvest scenario (all watersheds)

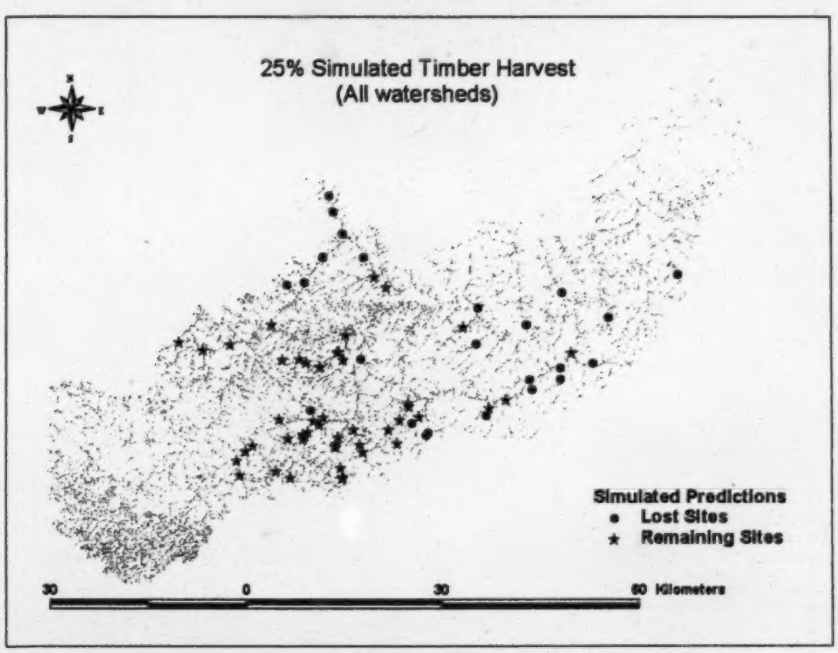

Figure 17. Simulated bull trout distribution from 25% timber harvest scenario (all watersheds)

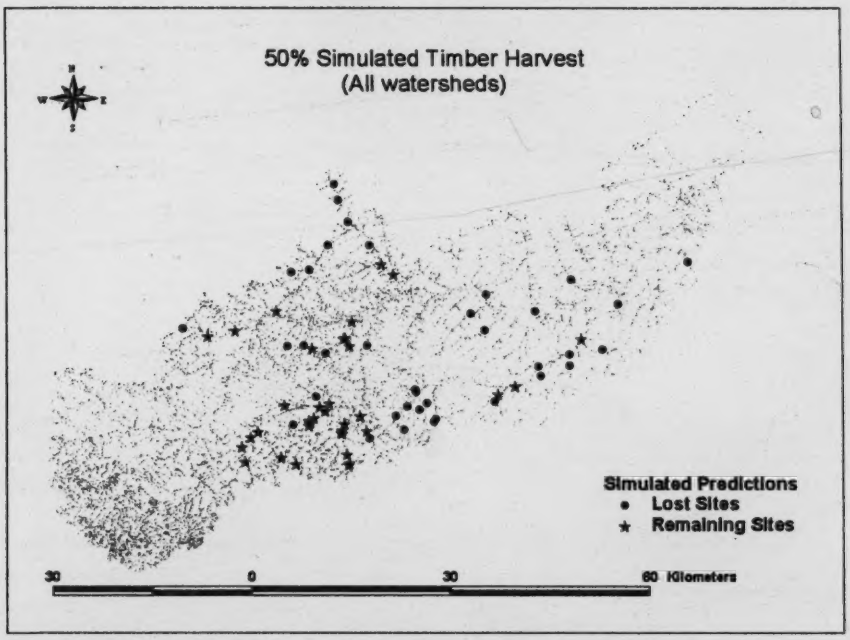

Figure 18. Simulated bull trout distribution from 50% timber harvest scenario (all watersheds)

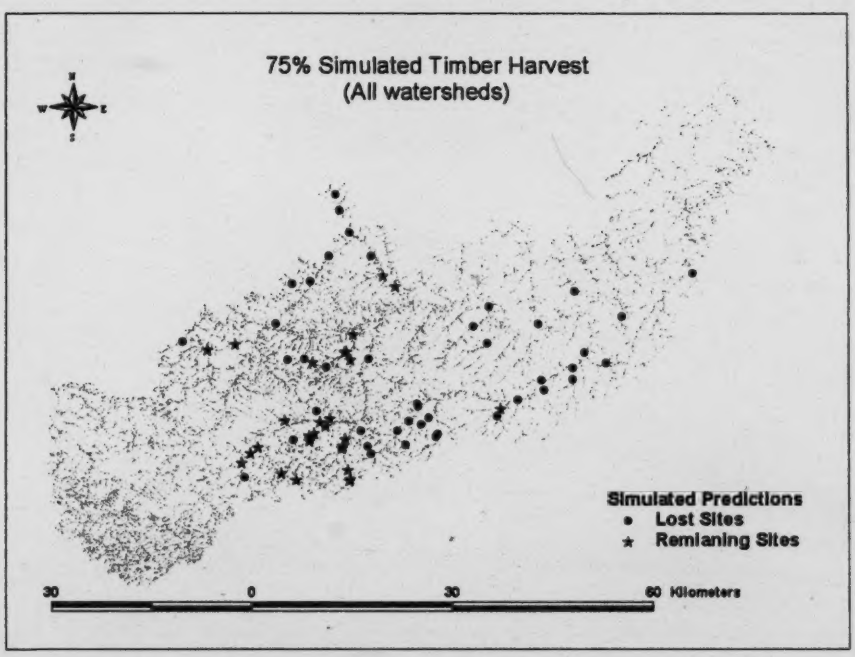

Figure 19. Simulated bull trout distribution from 75% timber harvest scenario (all watersheds)

CHAPTER 3

BULL TROUT (*Salvelinus confluentus*) HABITAT USE IN THE KAKWA RIVER WATERSHED, ALBERTA: LINKING OCCURRENCE AND ABUNDANCE

INTRODUCTION

Impacts on fish distribution and fish habitat from anthropogenic disturbances have been well documented (MBTSG 1998, Eaglin and Hubert 1993, Rieman *et al.* 1997, Reeves *et al.* 1993). In the previous chapter, I describe how bull trout occurrence is related to habitat, GIS and human disturbance parameters and explored the potential impacts timber harvest and road density has on bull trout occurrence. However, there is a tenuous link between the occurrence of bull trout and their abundance, which is information fisheries biologists and land use managers find most important. If the presence of bull trout at a particular location is noted, is the abundance of trout at that location reflective of the same attributes describing occurrence? Subsequently, when bull trout are present in particular habitats, I assume resources associated with the habitat they are selecting for are being used, and an abundance of these resources implies an increase in density of fish. I use the models developed for bull trout occurrence to investigate their relationship with relative abundance in the Kakwa River watershed. More importantly, I attempt to determine whether the predicted fish presence relates to relative abundance and the robustness of this relationship.

More recent evidence of bull trout declines throughout their historical range has prompted protection and recovery plans in many jurisdictions (Berry 1994, USFWS 2002). These plans require information on habitats within and across their existing range (Watson and Hillman 1997). Researchers report occurrence of bull trout at various

spatial scales and processes or factors that determine persistence (Rieman and McIntyre 1995). They elude to areas critical for continued viability (core areas) where bull trout populations may persist and become sources for repopulation of uninhabited streams. Streams may become devoid of bull trout because of fish passage barriers or impacts to aquatic habitats from a variety of natural or human caused disturbances.

Occurrence of bull trout at the Kakwa watershed scale indicates numerous sites having zero catches. Recently, there is considerable interest in models for count data that allow for excess zeros. Applications for these models is extending beyond evaluations of manufacturing defects (Lambert 1992) and road safety (Kockelman and Kweon 2001) to areas interested in species abundance (Welsh et al 1996). Abundance of bull trout was evaluated in a similar fashion, using a zero-inflated poisson regression model due to the preponderance of sites with zero captures (absent sites). Events with count data in nature tend not to conform to a poisson distribution and show over-dispersion in the data. When the variance of count data is greater than the mean, the data is said to be over-dispersed (Zorn 1996). I use poisson regression models that provide a standard framework for the analysis of (non-zero) count data (Ridout *et al.* 1998).

STUDY AREA

The Kakwa River watershed is located along the eastern Rocky Mountains in northwestern Alberta and is part of the Peace River drainage (Figure 20). The watershed encompasses 3,475 km^2 and, in addition to bull trout, supports several native fishes including Arctic grayling (*Thymallus arcticus*), mountain whitefish (*Prosopium williamsoni*), numerous cyprinids as well as non-native rainbow trout (*Oncorhynchus mykiss,* Table 12). Bull trout are the predominate fish within the watershed and have been reported in most of the tributaries to the Kakwa River. The Kakwa River originates at Kakwa Lake (B.C.) and flows northeast across alpine, sub alpine and boreal cordillera ecoregions, converging with the Smoky River.

The majority of the basin is located within the sub alpine and upper and lower cordillera ecoregion (Figure 21). Vegetation is dominated by conifer over story comprised of lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*). Stream elevations range from 660 m ASL near the confluence with the Smoky River to above 1900 ASL in the southwestern tributaries. Two sets of falls located on the Kakwa and South Kakwa rivers limit upstream migration. No bull trout have been documented above these falls. Bull trout remain in the watershed during all life stages and very few bull trout are known to migrate downstream out of the Kakwa River. Captured bull trout range in size from 45 to 731 mm fork length. Current industrial activities in the watershed include hydrocarbon extraction, seismograph exploration, road development and timber harvesting.

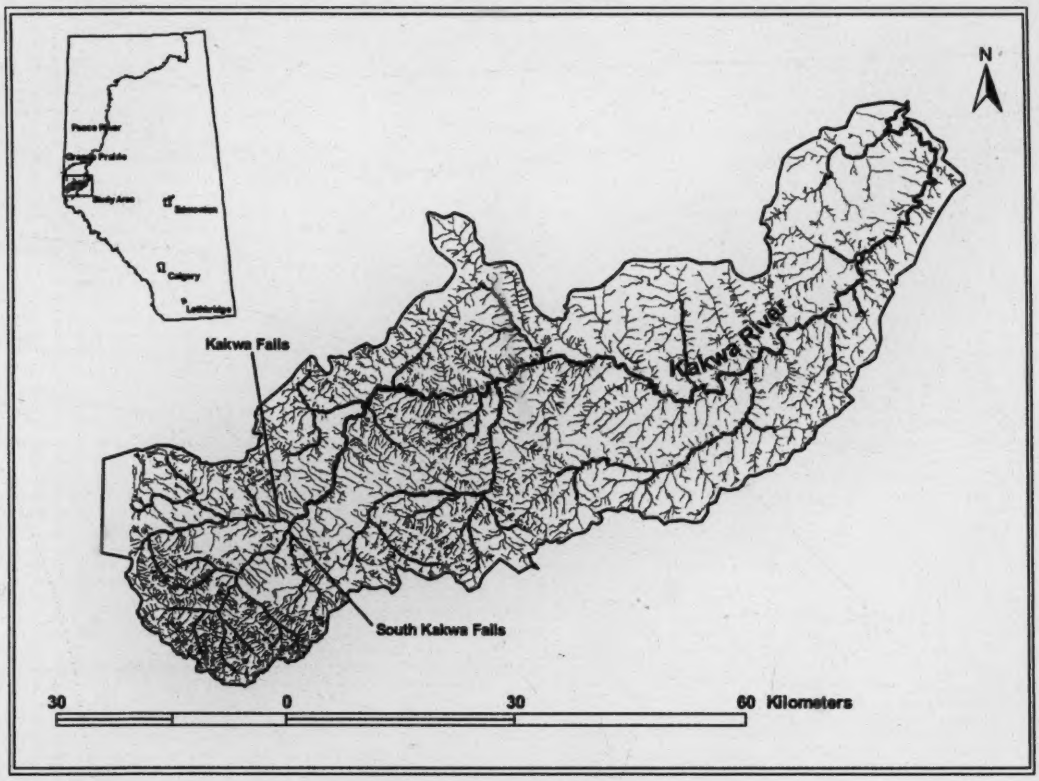

Figure 20. Kakwa River watershed in northwestern Alberta.

Table 12. Species distribution list in the Kakwa River watershed in alphabetical order. * denotes game fish

Family	Common Name	Scientific Name
Catostomidae	Longnose sucker	*Catostomus catostomus* (Forster)
	White sucker	*Catostomus commersoni* (Lacepède)
Cottidae	Slimy sculpin	*Cottus cognatus* Richardson
Cyprinidae	Lake chub	*Couesius plumbeus* (Agassiz)
	Longnose dace	*Rhinichthys cataractae* (Valienciennes)
Gadidae	Burbot	*Lota lota* (Linnaeus)
Percidae	Walleye*	*Sander vitreus vitreus* (Mitchill)
Salmonidae	Arctic grayling*	*Thymallus arcticus* (Pallas)
	Bull trout*	*Salvelinus confluentus* (Suckley)
	Mountain whitefish*	*Prosopium williamsoni* (Girard)
	Rainbow trout*	*Oncorhynchus mykiss* (Walbaum)

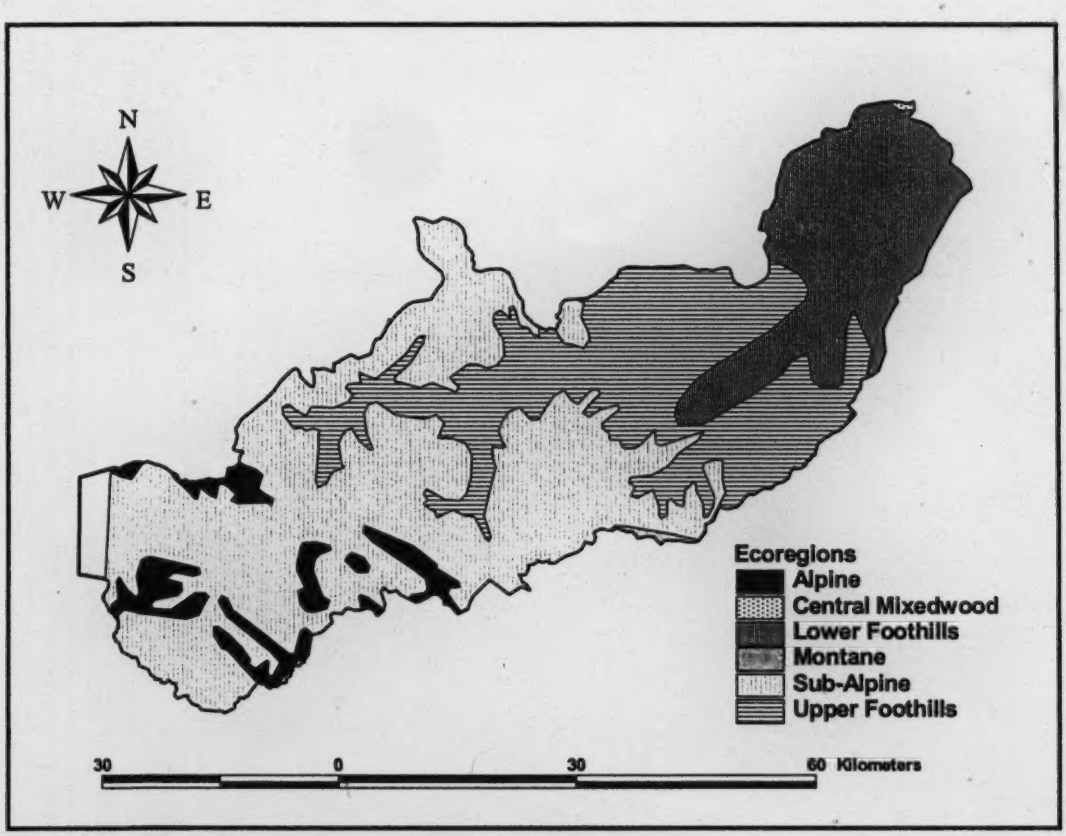

Figure 21. Ecoregions comprising the Kakwa River watershed.

METHODS

Data Collection

Sampling was conducted during the summer months from May to October of each year, after expected young of the year bull trout emergence. Sampling teams used a Smithroot™ Type 12 pulsed DC backpack electrofisher to capture trout with a capture detection probability of 0.74. All bull trout captured or observed were documented at each sample location. Sites with no bull trout present were given a value of zero. Sample sites were selected at random, ensuring representation of all stream orders (1st through 6th) to make certain captures of bull trout were representative across the drainage. Stream orders, defined by Strahler (1964) are related to stream size. I used the variables collected at stream reach and watershed levels obtained from the evaluation of bull trout occurrence in the previous section (Chapter 2). Abundance of bull trout at each site was converted to a measure of density (number of fish/100 m stream length).

Statistical Analysis

Prior to statistical analysis, I screened the data to test for normality and calculated descriptive statistics (mean, range, s.d., 95% confidence limits) to capture missing or extreme values. The poisson regression provides a standard framework for the analysis of spatially distributed abundance data. However, many sampling sites reported a preponderance of sites with zero captures of bull trout. The analysis resulted in data collected that were over-dispersed relative to the poisson distribution, with incidence of zero counts (sites with no captures) greater than expected for the poisson distribution. Using results from the logistic regression equations and resource selection predictive

probabilities in the previous chapter, I analyse the count data using a zero-inflated poisson (ZIP) technique to separate the analysis of count data from the zero count data in the samples. The base model is:

$$Y \sim Poisson(\mu)$$

where Y is the number of bull trout (density). The ZIP model is used when the proportion of bull trout catches (Y) is none and the remainder of the poisson parameter is the proportion of sites with bull trout catches. The poisson-distributed variable Y has equal mean and variance so that

$$E(Y) = Var(Y) = \lambda$$

and the poisson distribution is

$$\Pr(Y_i) = \frac{e^{-\lambda}\lambda^{Y_i}}{Y_i!}$$

I allow for covariates in the exponential fashion so that

$$\lambda_i = \exp(\beta' X_i)$$

Therefore the ZIP model is:

$$Y_i = 0 \text{ with Prob}(x)$$

$$Y_i \sim \text{Poisson } (\lambda_i) \text{ with Prob } (1\text{-}x)$$

so that

$$\Pr(Y_i = 0) = x + (1-x)\exp(-\lambda)$$
$$\Pr(Y_i > 0) = (1-x)\exp(-\lambda_i)\lambda_i^{Y_i} / Y_i!$$

The inflated portion of the model is tested against the best model describing occurrence of bull trout, using the zero inflated modeling technique (ZIP) in STATA 7.0 to evaluate density. To determine if the model is a candidate for zero inflated poisson regression, I

tested each inflated portion with the vuong statistic (Vuong 1989). The vuong test statistic distinguishes between non-poissonness due to overdispersion by comparing the full model with zero data against the count model (non-zero data). A significant result supports the use of the zero inflated model over the logistic model. Logistic regression outputs from the ZIP model are ranked using Akaike's information criteria (AIC, Burnham and Anderson 1998). AIC was calculated by adding $2K$ to the –2 log-likelihood value calculated from the regression where K is the number of parameters used in the model. Each inflated model was evaluated by the difference in AIC values from the best model (Δ_i) and the Akaike weights (ω_i) given to those models from the equation:

$$\omega_i = \frac{\exp(-0.5 \times \Delta_i)}{\sum_{r=1}^{R} \exp(-0.5 \times \Delta_i)}$$

I tested the deviance explained by the inflated portion of the model to determine which model type contributes the most to bull trout abundance. The explained deviance identifies how much the count portion of the model explains more than the full model. Predicted presence of bull trout was compared with the best model (lowest AIC) resulting from the zero inflated portion of the poisson regression.

RESULTS

In total, 172 sites were sampled in the Kakwa River basin. Ninety-seven sites had zero bull trout captures while the remaining 75 sites captured bull trout ranging between one to twenty nine fish. Densities ranged from 0.19 to 19.1 trout/100 m (Figure 22). Bull trout density was significantly related to elevation, with more bull trout found at sites sampled in higher elevations with significantly lower water temperatures ($p < 0.05$). Large frequencies of zeros were observed, relative to that expected from standard distributional assumptions. My data indicates over-dispersion of zero counts from sample sites that show high variance, compared to the mean (Table 13). To provide a link to the best occurrence models, all model types were inflated against the best occurrence model that included the percent of fines, level of timber harvest and stream order (Table 14). The model incorporating habitat and GIS variables offered the best explanation of count data for bull trout ($\omega_i = 0.97$).

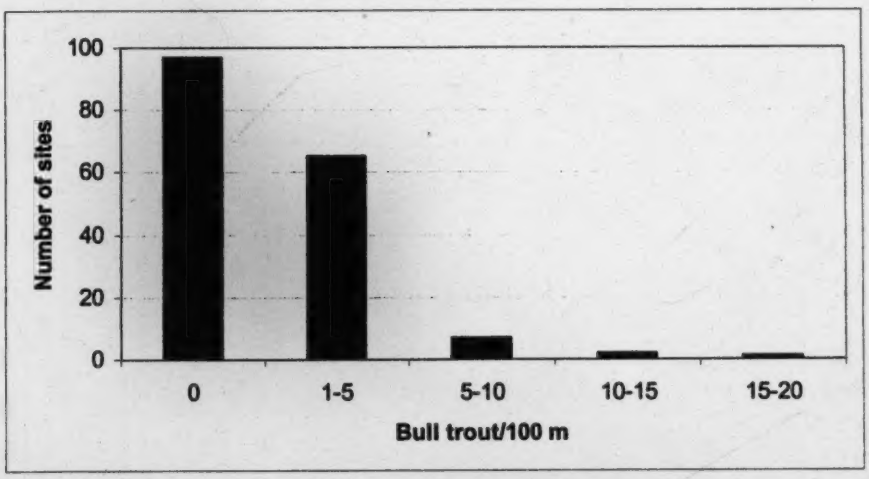

Figure 22. Distribution of bull trout density from 172 sites sampled in the Kakwa River basin. Density of trout represents the number of trout per 100 m of stream length.

Table 13. Descriptive statistics for bull trout counts (number) and density (number bull trout/100 m). Large variance suggests over-dispersion of the data.

Variable	N	Minimum	Maximum	Mean	s.d.	Variance
Bull trout count	172	0	29.0	2.017	4.42	19.54
Bull trout density	172	0	19.1	0.888	2.16	4.65

Table 14. Zero inflated models evaluating bull trout abundance. Each model type incorporates respective attributes based on occurrence model results. β values, standard error and deviance (D^2) calculated from the logistic regression. Change in AIC (Δ_i) based on difference of each candidate model from the best model type. Weighted AIC (ω_i) indicates the normalized relative likelihood of the AIC value approximating the weight of evidence of each model type to other candidate models, Z is the vuong test statistic.

Model Type	Variable	β	S.E.	D^2	Δ_i	ω_i	Z
Habitat Only	Fines	-0.015	0.006	4.2	120.2	0.000	0.001
	B_width	+0.034	0.008				
GIS Only	Str_ord	+0.583	0.069	19.0	6.9	0.030	0.001
	Elev	+0.003	0.000				
Human Disturbance	P_watershed_CC	-6.276	1.365	5.9	107.0	0.000	0.000
	Den_c_km	-0.056	0.460				
Habitat/GIS	Str_ord	+0.550	0.071	20.4	0.00	0.970	0.002
	Fines	+0.004	0.007				
	Distance	+0.002	0.001				
	Elev	+0.004	0.000				
Habitat/ Human Disturbance	P_watershed_CC	-5.157	1.345	7.2	101.1	0.000	0.000
	Den_c_km	-0.071	0.460				
	B_width	+0.022	0.008				
	Den_all_cross	+0.071	0.064				
GIS/ Human Disturbance	P_watershed_CC	-6.159	1.471	12.4	59.4	0.000	0.001
	Den_c_km	+0.541	0.495				
	Str_ord	+0.451	0.067				
Habitat/GIS /Human Disturbance	Fines	-0.010	0.008	12.5	58.6	0.000	0.004
	P_watershed_CC	-5.511	1.381				
	Str_ord	+0.428	0.067				

The percent deviance explained indicates the habitat-GIS model added 20% explanation when separating the count data from the zero data. Similar to the occurrence model, increases in stream order, distance fished and elevation positively contributed to abundance, however in this instance, fine sediment was also a positive contributor. The model incorporating GIS variables alone also did well in describing density of bull trout, explaining an additional 19% of the deviance from the best occurrence model. When the habitat/GIS/Human disturbance model was inflated against itself, beta values from both the inflated and non-inflated models remained similar, with amount of fine sediment and timber harvest having a negative relationship and stream order a positive one. Differences in beta values show a small increase in the timber harvest parameter and slight decreases in both the amount of fine sediment and stream order (Table 15). All models showed a high significance for the vuong statistic ($p < 0.05$) supporting the inflation (ZIP) model.

Density of bull trout from the best ZIP model (Habitat/GIS) was evaluated against the predicted resource selection function from the occurrence model (Figure 23). The probability of bull trout presence shows an increase in predicted abundance when the predicted presence increases.

Table 15. Differences in beta values from the best occurrence model (non-inflated) and the inflated portion of this model identifying density of bull trout.

Model Type	Variable	Non-Inflated	Inflated	Difference
Habitat/GIS/Human	Fines	-0.024	-0.010	+0.014
Disturbance	P_watershed_cc	-5.405	-5.511	-0.106
	Str_ord	+0.737	+0.428	+0.309

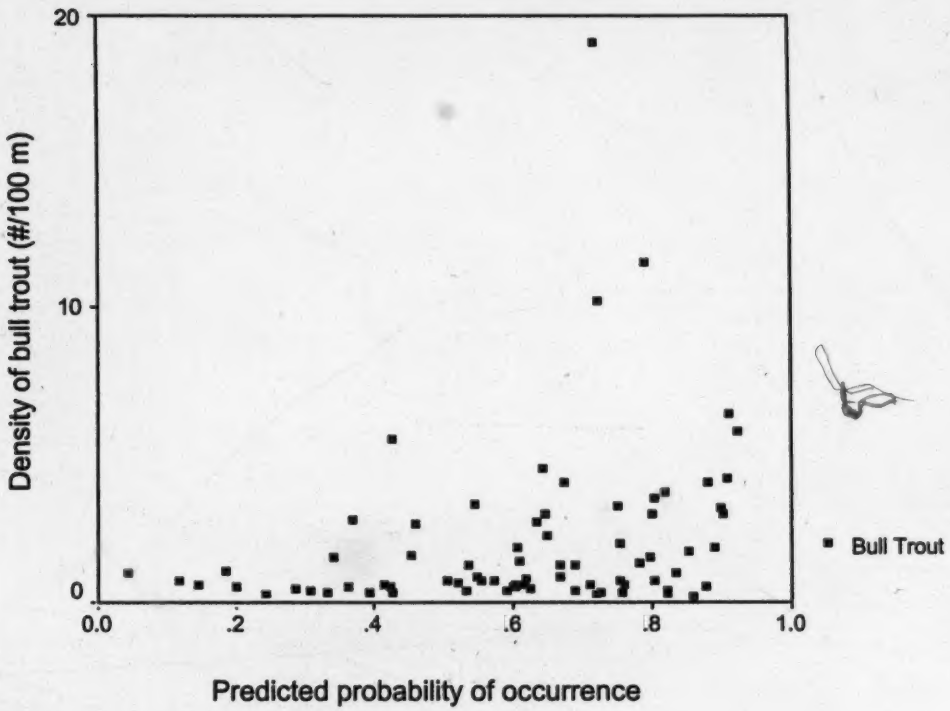

Figure 23. Scatter plot of predicted probability of bull trout presence against the density of bull trout found at each sample site. Predicted presence is derived from the output of the resource selection function for the habitat/GIS model.

DISCUSSION

The use of zero-inflated measures for data with many zeros versus counts is a useful method to characterize the density of bull trout. Analysis shows that models with variables important for presence or absence are not necessarily the same for evaluating density. Bull trout have selected for sites where streams were typically larger, had low levels of fine sediment and little timber harvest in the adjacent watershed. These areas likely provide for higher levels of invertebrates, small fish and overhanging cover (Ben-James 2001), important for feeding and rearing of young trout. The abundance model suggests that an increase in density of trout is reflected by one similar variable, stream order. Other determining factors relating to abundance are elevation and slight increases in fine sediment. Distance fished with electrofishing was in the model, and as expected, increasing the proportion of stream fished, the higher the probability of catching trout.

Increases in elevation were significantly related to increased density ($p < 0.01$), similar to the occurrence model where more sites with trout were found at higher elevations. The combination of both models indicates higher densities of trout are supported by the higher predicted probabilities that trout will be found at those locations. Resources associated with those locations are important for them to be captured, evidenced by the abundance model. Larger streams at higher elevations are typically where the influence of groundwater occurs, primarily in areas with topographic knickpoints where elevation changes are dramatic. Baxter and Hauer (2000) refer to these areas as bounded alluvial valley segments (BAVS) where bull trout select for spawning. Three streams (Grizzly, Lynx and Copton creeks) are larger 5th order streams located at elevations ranging from 1130 m (Lynx) to 1318 m (Grizzly), show evidence of

BAVS. Densities at these locations were moderate to high, and no timber harvest has occurred. Based on the occurrence model, these areas are predicted to retain bull trout when harvest simulations are applied to the Kakwa watershed.

While these results indicate two separate models that account for occurrence and abundance, it should be noted that the sample sites with zero catches of bull trout were strongly linked with timber harvest. There is a strong assumption that because timber harvest negatively impacts on fish occurrence (this research, Reeves *et al* 1993, Murphy *et al* 1986), those sites evaluated for density would be segregated from sites influenced by clear cutting. Results indicate timber harvest was only 5.8% in watersheds where bull trout were present, whereas areas where bull trout were absent timber harvest exceeded 16%. Therefore, the best model accounting for density would be different than the best model identifying occurrence because where harvest levels are high, bull trout are more likely to be absent (density is zero). The ZIP model evaluates that portion of the data with counts (separate from zeros) and would not strongly identify with timber harvest because many sites have zero bull trout captures in harvested areas. However, implications arising from human disturbance may influence density of bull trout where low density sites dominate in areas with high timber harvest. Low density sites (<1 bull trout/100m) were found in watersheds were timber harvest was 9.7%, whereas densities from 1-3 and >3 fish/100m were located in areas where timber harvest was only 1.3 and 0.1%, respectively (Figure 24)

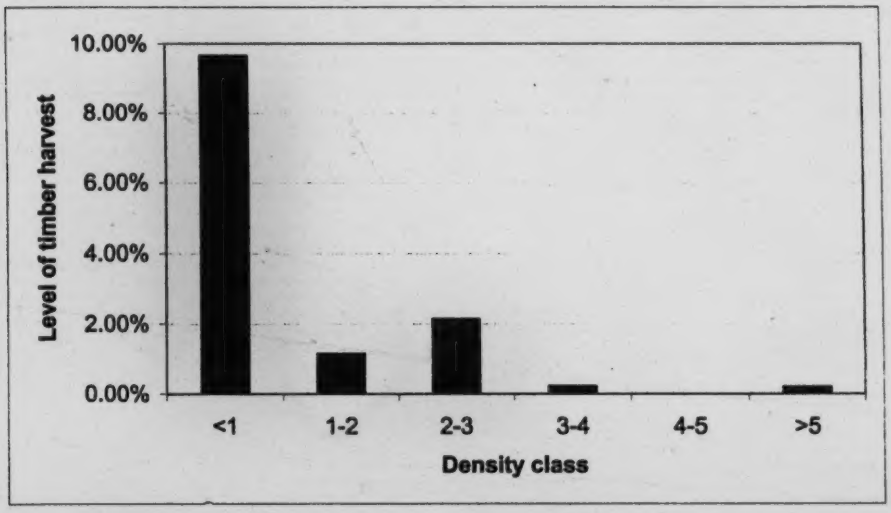

Figure 24. Corresponding levels of timber harvest associated with each density class (number of bull trout/100 m) in the Kakwa River watershed.

Different models are useful when determining occurrence or abundance. However, anthropogenic perturbations of the aquatic environment may not equally contribute to maintenance of fish populations that vary over time (Boisclair 2001). These data were collected over a relatively short period of time and do not account for temporal changes in fish density. There remains, however, a strong link between the density of fish and levels of timber harvesting occurring in the Kakwa watershed, which may not be captured with the zero inflated poisson regression models. Combining the occurrence and abundance models indicate that predicted increases in occurrence were related to increased abundance at those sites. This relationship is useful when determining timber harvest levels in currently non-harvested watersheds and for recovery of bull trout in areas where densities are low. Knowing what attributes play a role in determining occurrence will be useful for increasing abundance because of the relationship density has to predicted probability of bull trout presence.

REFERENCES

Baxter, C.V. and F.R. Hauer. 2000. Geomorphology, hyporheic exchange and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1470-1481.

Ben-James, B. 2001. The feeding ecology of juvenile bull trout, *Salvelinus confluentus*, in an Eastern Cascade stream. Pg 59 in Brewin, M.K., A.J. Paul, and M. Monita, editors. Bull Trout II Conference Proceedings. Trout Unlimited Canada, Calgary, Alberta.

Berry, D.K. 1994. Alberta's bull trout management and recovery plan. Unpublished report. Alberta Environmental Protection, Fish and Wildlife Service. Edmonton, AB.

Boisclair, D. 2001. Fish habitat modeling: from conceptual framework to functional tools. Canadian Journal of Fisheries and Aquatic Sciences 58: 1-9.

Boyce, M.S., P.R. Vernier, S.E. Nielson, and F.K.A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological modelling 157: 281-300

Burnham, K.P. and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. New York: Springer-Verlag. 353 pp.

Eaglin, G.S. and W.A. Hubert. 1993. Effects of logging roads on substrate and trout in streams of the Medicine Bow National Forest, Wyoming. North American Journal of Fisheries Management 13:844-846.

Kockelman, K.M. and Y. Kweon. 2001. Driver injury severity: An application of ordered probit models. Accident analysis and prevention. Available online at: http://www.ce.utexas.edu/prof/kockelman/public_html/AAPSubmission--InjurySeverity.pdf

Lambert, D. 1992. Zero-inflated poisson regression, with an application to defects in manufacturing. Technometrics 34: 1-14.

MBTSG (Montana Bull Trout Scientific Group). 1998. The relationship between land management activities and habitat requirements of bull trout. Unpubl. Rpt. Prepared for The Montana Bull Trout Restoration Team. Montana Department of Fish, Wildlife and Parks, Helena, Montana. 78p.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaska streams. Canadian Journal of Fisheries and Aquatic Sciences 43:1521-1533

Reeves, G.H., F.H. Everest, and J.R. Sedell. 1993. Diversity of juvenile anadromous salmonid assemblages in Coastal Oregon Basins with different levels of timber harvest. Transactions of the American Fisheries Society 122: 309-317

Ridout, M., C.G.B. Demétrio, and J. Hinde. 1998. Models for count data with many zeros. International Biometric Conference, Cape Town. Available online at: http://www.ukc.ac.uk/IMS/personal/msr/ibc_fin.pdf. 13 pp.

Rieman, B.E. and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. 124: 285 – 296.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17: 1111-1125.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks; Section 4-2 in: Handbook of Applied Hydrology, Van Te Chow ed. McGraw-Hill, New York

USFWS (United States Fish & Wildlife Service). 2002. Bull trout (*Salvelinus confluentus*) draft recovery plan. Available online at: http://pacific.fws.gov/bulltrout/recovery/Default.htm

Vuong, Q.H. 1989. Likelihood ratio tests for model selection and non-nested hypotheses. Econometrica 57: 307-333.

Watson, G. and T.W. Hillman. 1997. Factors affecting the distribution and abundance of bull trout: An investigation at hierarchical scales. North American Journal of Fisheries Management 17: 237-252.

Welsh, A., R. Cunningham, C. Donelly, and D. Lindenmayer. 1996. Modeling the abundance of rare species – statistical-models for counts with extra zeros. Ecological Modelling 88: 297-308.

Zorn, C.J.W. 1996. Evaluating zero-inflated and hurdle poisson specifications. Midwest Political Science Association. Available online at: http://web.polmeth.ufl.edu/papers/96/zorn96.pdf. 16 pp.

CHAPTER 4

CONCLUSION

Distribution of bull trout was evaluated from electrofishing sites across the Kakwa River watershed, Alberta. Sample sites were randomly selected to ensure all stream orders, ranging from one to six were evaluated. The use of electrofishing had a probability of detection close to 0.75, indicating on average that bull trout may have been present 25% of the time in sites where no trout were found. Bull trout were predominately found in stream orders 3 through 5, typical of areas where spawning and rearing takes place (Hvenegaard and Fairless 1998, Post and Johnston 2002, Rieman and McIntyre 1995), at elevations ranging from 1300 m to 1600 m. Catches of trout were significantly related to stream water temperature with the highest catches found when temperatures were between 7 and 11°C. Temperatures were significantly colder at higher elevations.

Resource selection functions were used to develop models that describe values proportional to the use of resources by bull trout. Candidate occurrence models were developed using logistic regression to identify important variables contributing to predicted presence of bull trout in the watershed. Candidate models were initially separated into three broad categories (Habitat, GIS, Human disturbance) and eventually combined to determine the best predictive model. Models using habitat variables alone did poor in describing bull trout occurrence. Fine sediment levels were a strong attribute in two of the three habitat candidate models and consistently showed a negative relationship with bull trout presence. Understandably, bull trout depend on clean water and gravels that are free of sediment for spawning and rearing which prevents eggs from

being suffocated during incubation over the winter months (Post and Johnston 2002). Stream bankfull width was also a strong attribute and was positively associated with increased presence of trout. GIS model attributes indicated bull trout selected for streams that were larger in size at higher elevations. Human disturbance models indicated a strong negative relationship with increased levels of timber harvest and road density. Number of stream crossings was shown to have a higher predicted occurrence of bull trout, which may likely be due to pooling of trout at crossings that are impassable to fish.

Overall, the best logistic model predicting occurrence of bull trout was a combination of attributes from all three candidate models which included stream order, level of fine sediment and percent of timber harvest. Based on this model, bull trout selected for sites with lower level of timber harvest and fine sediments and larger stream size. Although temperature was not an attribute in any candidate model, water temperatures were significantly higher in streams where adjacent timber harvest occurred and lower in streams at higher elevations. This research suggests that bull trout select for areas with low timber harvest levels having lower water temperatures and higher elevations where timber harvest was less prevalent. There was a weak correlation between timber harvest and elevation, and while these data suggest a relationship exists, further experimentation is required. However, simulated increases in timber harvest levels across all elevations in the watershed, based on the best logistic model, indicated a decline in bull trout occurrence. Therefore, despite bull trout selecting for high elevations, once these areas are logged, there is a predicted decrease in bull trout sites, that may be associated with increased water temperatures or other factors limiting production such as increased levels of fine sediment or disruption in water flows.

Density of bull trout was evaluated using zero-inflated poisson regression (ZIP) to separate count (areas with bull trout) from zero data (bull trout absence) to determine attributes associated with abundance. These regressions were tested against the best logistic model describing occurrence. Overwhelmingly, stream order, level of fine sediment, elevation and the distance fished were the best predictors in determining abundance. All of these attributes showed a positive relationship with bull trout density. Both stream order and elevation were also strong predictors in the occurrence model. Combining the occurrence and abundance models indicate that predicted increases in occurrence were related to increased abundance at those sites. This relationship is useful when determining timber harvest levels in currently non-harvested watersheds and for recovery of bull trout in areas where densities are low. Knowing what attributes play a role in determining occurrence will be useful for increasing abundance because of the relationship density has to predicted probability of bull trout presence.

Occurrence of groundwater, important for maintaining constant flow and regulating stream temperature (Baxter and Hauer 2000, Baxter and McPhail 1999), often fall within the sizes of streams bull trout are present in the Kakwa watershed. Dunham and Rieman (1999) suggest these habitats are positively related to bull trout persistence. Predictive simulations from this research reinforce this concept of core habitats, with the remaining sites where bull trout persist directly related to where the spawn and rear, currently protected by a "Class A" stream designation under the Alberta Water Act (Ministerial Regulations 1999). These streams have been selected by this designation to limit human disturbance in and around important, critical habitats necessary for

prolonged maintenance of bull trout populations by restricting crossings of roads and pipelines.

This research has shown that impacts from human disturbance have detrimental effects on bull trout occurrence. Where bull trout do persist, elevated levels of timber harvest have resulted in a reduced density of bull trout. Complex habitats that support bull trout are impacted in some fashion by these disturbances. Linking the mechanisms of human perturbations to distribution and abundance of bull trout remains an ongoing topic of research, although it is clear that new, innovative methods of extracting renewable and non-renewable resources must be emphasized if these complex habitats are to remain intact.

The overall model describing occurrence is different than the best inflated model describing abundance. However, linking these models has shown to be effective at predicting densities based on predicted presence. Loss of sites containing bull trout result in reduced densities across the Kakwa watershed. Lower density sites are located in areas where timber harvest has occurred. The high density sites associated with bounded alluvial valley segments are associated with groundwater upwelling, important for spawning success of bull trout populations. Maintenance of these areas is key to the continued viability of bull trout in the Kakwa River watershed over time. Lower density sites, that appear to be lost first with increased timber harvest simulations, should be managed to ensure protection, recovery and the continued use of bull trout remains or improves.

REFERENCES

Baxter, C.V. and F.R. Hauer. 2000. Geomorphology, hyporheic exchange and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1470-1481.

Baxter, C.V. and J.D. McPhail. 1999. The influence of redd site selection, groundwater upwelling and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Zoology 77: 1233-1239.

Dunham, J.B. and B.E. Rieman. 1999. Metapopulation structure of bull trout: Influences of physical, biotic and geometrical landscape characteristics. Ecological Applications 9: 642-655.

Hvenegaard, P.J. and D. Fairless. 1998. Biology and status of bull trout (*Salvelinus confluentus*) in the Kakwa River drainage, Alberta. A fisheries management enhancement project, Alberta Conservation Association. Data summary 1995 to 1997 Progress Reports. Alberta Conservation Association, Northwest Boreal Region, Peace River, AB. 30 p.

Ministerial Regulations 1999. *Water Act*, Province of Alberta. Assented 1996, proclaimed 1999. Queens Printer for Alberta.

Post, J. R. and F. D. Johnston. 2002. Status of the Bull Trout (*Salvelinus confluentus*) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association, Wildlife Status Report No. 39, Edmonton, AB. 40 pp.

Rieman, B.E. and J.D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. 124: 285 – 296.